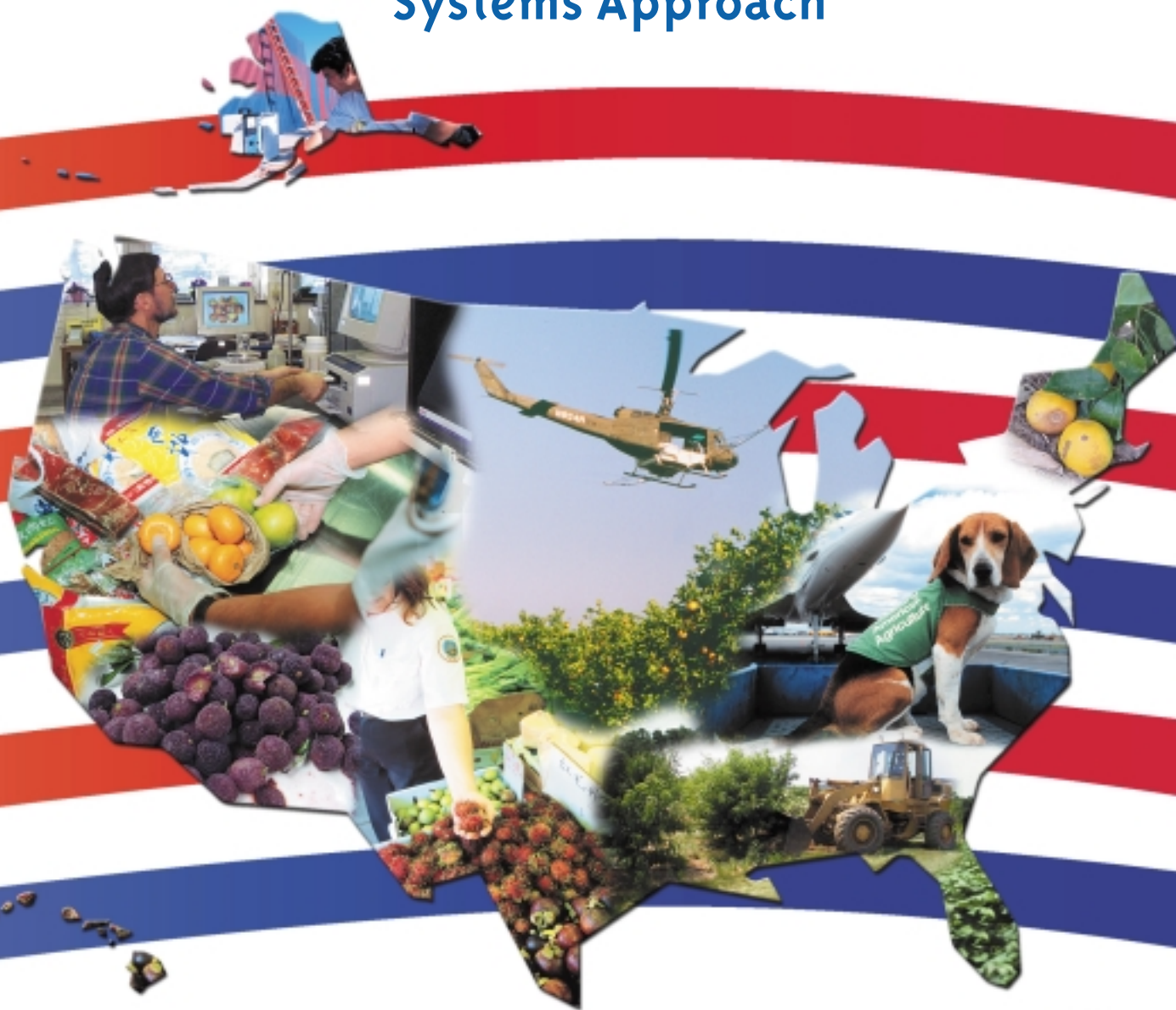


PREVENTING THE INTRODUCTION OF PLANT PATHOGENS INTO THE UNITED STATES: The Role and Application of the “Systems Approach”



A scientific review coordinated by The National Plant Board
for The United States Department of Agriculture
Animal and Plant Health Inspection Service
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PREFACE

Quarantines have been used for thousands of years to provide protection against pests and diseases affecting animals, plants and humans. People with leprosy were quarantined in Biblical times and this practice continues in some parts of the world even to this day.

Plant pest quarantines identify a regulated area and name the pest that is to be excluded from a particular area and/or targeted for preventing further spread within a defined area. They also specify the articles that are regulated. The movement of certain articles may be prohibited. Movement may be restricted for others. Typically, articles produced and maintained in areas free of the quarantine pest are allowed to move into a protected area, provided they are accompanied by a certificate stating that they originate in a recognized pest free area.

Treatments often are prescribed for regulated articles as a basis for pest risk mitigation and certification by authorized officials. Historically, chemical fumigation, heat or cold applied for specified time periods and under prescribed conditions, and other single treatments were required as a condition for certification and movement outside of the quarantined area.

In recent years, quarantines have prescribed various combinations of pest risk mitigation methods or treatments as a condition for certification and movement. These combinations have been created by selecting risk mitigation methods from available options including requirements for: pest free planting stock, growing media, cultural practices, area-wide pest management, pest monitoring as a trigger for a specified chemical treatment, fruit maturity or harvest period standards, harvest methods, sorting, packaging and handling facilities, and post-harvest treatment.

Given the foregoing, although not often thought of that way, quarantines that require a combination of risk mitigation methods, in themselves, represent Systems Approaches to pest risk mitigation. The quarantine itself is simply an instrument for legally effecting the Systems Approach that was developed for the purpose of reducing the identified pest risk to an acceptable level.

Global trade interests have driven the development of trade agreements that affect the application of plant pest requirements (phytosanitary requirements) among trading partners. Generally, trade agreements recognize the sovereign right of countries to protect themselves from the harm that serious pests could cause to a country's agriculture, natural resources, environment, economy, and public health.

However, with agreement on the phase-out of specified commodity tariffs, a basic concern was that countries could resort to the use of phytosanitary requirements as non-tariff trade barriers. Accordingly, the United Nations World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), which became effective on January 1, 1995, includes disciplines aimed at minimizing or preventing the use of sanitary and phytosanitary requirements as disguised, unjustified trade barriers. The SPS also includes a dispute resolution process.

The SPS agreement names the International Plant Protection Convention (IPPC) as the international organization responsible for phytosanitary standard setting and harmonization of phytosanitary measures affecting trade. See additional IPPC information at:

<http://www.fao.org/waicent/FaoInfo/Agricult/AGP/AGPP/PQ/default.htm>

The IPPC has encouraged countries to ensure, through phytosanitary certification, that their exports are not the means for introducing new pests to their trading partners. Importing countries work to ensure that the measures they require for protection are technically justified.

The IPPC also includes non-binding dispute settlement procedures that can be applied when one country believes another country's phytosanitary requirements constitute unjustified barriers to trade. Although the dispute settlement process in the IPPC is non-binding, the results of the process can be expected to have substantial influence in disputes that, under the SPS Agreement, may be elevated to the World Trade Organization for resolution.

The United States participated in the negotiations that led to the SPS agreement. It is a party to both the SPS agreement and the IPPC. The United States also is active in the standard setting process that takes place under the auspices of the IPPC and the North American Plant Protection Organization. The U. S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (PPQ) is the national plant protection organization responsible for the application of phytosanitary standards in the United States.

Phytosanitary standards of many types have been developed to guide the application of trade and other agreements. The IPPC's International Standards for Phytosanitary Measures (ISPM) No. 11, "Pest risk analysis for quarantine pests," is a standard that governs pest risk assessment. Countries must establish SPS measures on the basis of an appropriate assessment of the actual risks involved. When requested to do so, they are required to make known what factors they took into consideration, the assessment procedures they used and the level of risk they determined to be appropriate. Thus, determining the appropriate level of risk is essential to determining what risk mitigation measures a country requires to reduce the identified level of risk to an appropriate level.

A May 2001 draft IPPC standard, currently out for country consultation, is "Integrated Measures for Pest Risk Management (Systems Approaches)" (ISPM No.13). This draft standard was reviewed, considered, and cited extensively in this report. The U. S. Department of Agriculture is participating in the country consultation process. It is expected that this standard will be adopted by the International Plant Protection Convention in April 2002.

As shown in this report, there is no question that the PPQ possesses the capacity, experience and commitment to fulfill its plant safeguarding responsibilities in full compliance and harmony with international trade agreements, conventions and phytosanitary standards, including standards relative to the Systems Approach for plant pathogen risk mitigation associated with proposals to import plants or plant products into the United States. The evidence is that this has been its history and will be its future.

Bill L. Callison, President
National Plant Board

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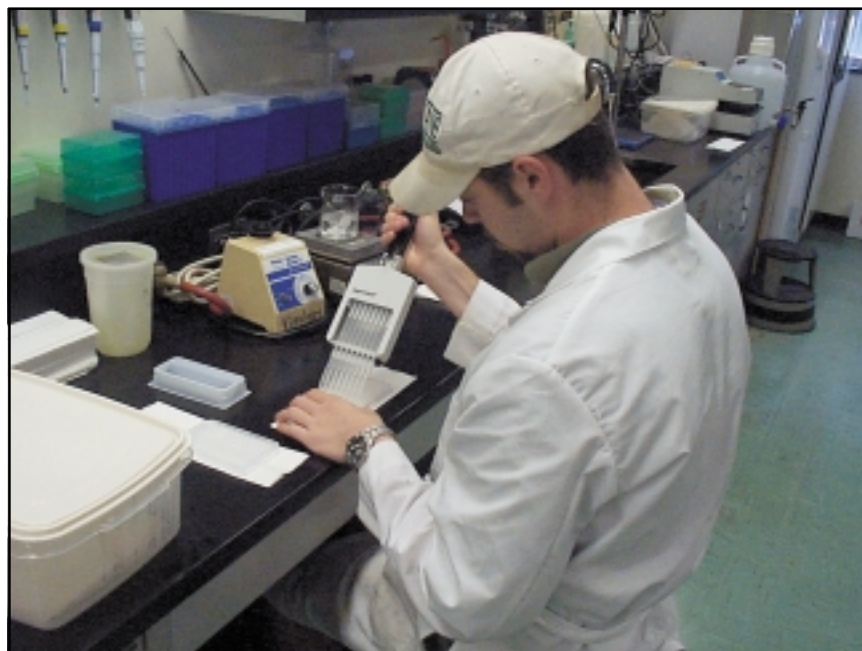
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EXECUTIVE SUMMARY

This study of the Systems Approach was mandated by the U.S. Congress at the request of agricultural commodity groups. Accordingly, throughout the study the definition of Systems Approach found in the Plant Protection Act [7 USC 7712 (e) Section 412 (e)] is used. The Plant Protection Act describes Systems Approaches as:

“[A] defined set of phytosanitary procedures, at least two of which have an independent effect in mitigating pest risk associated with the movement of commodities.”

Major Conclusions:

- 1) The available alternatives to Systems Approaches either may provide inadequate protection or result in unacceptable outcomes. Yet, some of these same alternatives can be combined to provide the desired level of protection in balance with other considerations such as cost-efficiency, environmental impact and marketability of the commodity. Such instances, then, are the foremost examples of the risk situations best managed by Systems Approaches.
- 2) As such, Systems Approaches are analogous to the more familiar Integrated Pest Management (IPM) programs with these important distinctions:
 - IPM programs are designed to minimize the economic impact of a pest complex, while,
 - Systems Approaches currently in use are designed to reduce the risk of introduction and/or establishment of a pathogen or pathogens to a level commensurate with that achieved through quarantine or prohibition of import.
- 3) Both the theoretical framework and the currently approved Systems Approaches for pathogen risk mitigation are scientifically sound specifically when:
 - A combination of the measures results in an increased level of phytosanitary security unattainable via the application of a single mitigation measure, and
 - Effectiveness can be evaluated and stated in either or both quantitative and qualitative terms.
- 4) Data- and knowledge-based requirements as well as regulatory expectations are adequately defined within those Systems Approaches currently approved by the Animal and Plant Health Inspection Service.
- 5) There are established and valid methods for assessing the performance of Systems Approaches provided the goals are adequately delineated.
- 6) Currently, stakeholder input in rulemaking, development and verification of Systems Approaches is lacking. In fact, current guidelines for implementation sometimes inhibit such input. A process proven to be effective in developing systems is systems engineering.

Recommendations:

- 1) A process for inclusion of stakeholder input in the development of Systems Approaches is needed. We recommend that principles of Systems Engineering be implemented to ensure stakeholder input shapes the rulemaking, development and verification of Systems Approaches.
- 2) Systems Approaches should be implemented *only* when there is sufficient research to support the acquisition and maintenance of the essential knowledge and data, thus allowing decision-makers to:
 - Quantify the effectiveness of individual mitigation measures,
 - Estimate the availability and impact of systems requirements on the development of an appropriate suite of mitigation measures, and
 - Direct the development of novel control and management techniques where existing methods cannot be fit to the system operation requirements.



I. PURPOSE

When a single treatment method for mitigating the risk of introduction and establishment of an exotic pest is unknown, unavailable or ineffective at reducing the risk to an acceptable level, two or more independent treatments have been combined. Each treatment, then, reduces pest risk by some level to achieve an overall acceptable level of risk for pests that infest or hitchhike on a particular commodity. This approach to pest risk mitigation has been called the Systems Approach. The term was first used in 1994 to describe an insect management system developed to reduce the quarantine pest risk associated with the importation of avocados from Mexico (Miller, *et al*, 1995).

The purpose of this study is to satisfy the requirements of Title IV, Section 412(e) of the Agricultural Risk Protection Act of 2000. The Act requires the Secretary of the United States Department of Agriculture (USDA) to “conduct a study of the role for and application of Systems Approaches designed to guard against the introduction of plant pathogens into the United States associated with proposals to import plants or plant products into the United States.” Congress required that the study involve participation by scientists from state departments of agriculture, colleges and universities, the private sector, and the USDA Agricultural Research Service (ARS).

Private industry, both domestically and internationally, commonly uses Systems Approaches as normal disease management practices during the course of commodity production, shipping, and marketing. The USDA has also utilized Systems Approaches as a regulatory tool in the mitigation of plant pests on imports. Systems Approaches are designed for incorporation into a regulatory framework whereby foreign commodities may be imported into the United States with minimal risk of quarantine plant pathogen introduction. Without this framework, pathogen infested, high-risk commodities would find their way into our markets and production sites through illegal means and without safeguards. Despite this fact, the USDA’s use of Systems Approaches has, in some cases, been questioned, hence the request by the Congress for the conduct of this study. Recognizing the need to ensure an unbiased evaluation of the use of Systems Approaches, the USDA sought input from stakeholders through a formal review process.

The United States Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine Program (PPQ) is responsible for safeguarding American agriculture and natural resources. This includes preventing the harm that serious plant pathogens can cause. State departments of agriculture also have a critical, vested interest in ensuring that harmful pests, including pathogens, are kept out of the United States. The National Plant Board (NPB) is the organization that represents and is comprised of the U.S. state plant regulatory agencies that provide leadership in plant protection and certification, pest prevention and management, while striving to harmonize efforts to protect American agriculture, forestry, horticulture and the environment from harmful organisms. The USDA requested that the NPB coordinate this study.

The USDA-APHIS-PPQ Center for Plant Health Science and Technology formed a steering committee composed of APHIS-PPQ, USDA-ARS and NPB representatives to provide guidance, oversight, and logistical support throughout the review process. The steering team, in turn, ensured that scientists from state departments of agriculture, colleges and universities, the private sector, and ARS had an opportunity to participate.

Steering Committee

- Robert Balaam, New Jersey Department of Agriculture, Trenton, New Jersey (co-chair)
- Dr. Alan Dowdy, USDA-APHIS-PPQ, Center for Plant Health, Science & Technology, Raleigh, North Carolina (co-chair)
- Dr. Lawrence Brown, USDA-APHIS-PPQ, Center for Plant Health, Science & Technology, Raleigh, North Carolina
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- Edwin Imai, USDA-APHIS-PPQ, Riverdale, Maryland
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- Dr. Matthew H. Royer, USDA-APHIS-PPQ, Invasive Species and Pest Management, Riverdale, Maryland
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Under a cooperative agreement with APHIS-PPQ, the National Plant Board assembled a study team of external stakeholders composed of representatives from state departments of agriculture, academia, private industry, and ARS. The background of the study team was founded in science and not the regulatory arena. Hence, some of the terms used by the team in this report may not have the same meaning as those customarily used in the international regulatory arena. If a term is unclear, please consult the **Glossary** (beginning on page 78). The usage will follow the definitions found there.

Study Committee

- Dr. O.W. Barnett, Plant Pathologist, North Carolina State University, Raleigh, North Carolina (chair)
- Dr. Edwin Civerolo, Plant Pathologist, USDA-ARS, Davis, California
- Dr. Conrad Krass, Plant Pathologist, California Department of Food and Agriculture, Sacramento, California
- Dr. Dave Mortensen, Weed Scientist and Systems Agriculture, The Pennsylvania State University, State College, Pennsylvania
- Dr. Sally Schneider, Plant Pathologist/Nematologist, USDA-ARS, Fresno, California
- Dr. David Smith, Plant Pathologist, Monsanto, DeKalb, Illinois
- Andy LaVigne, Executive Vice President, Florida Citrus Mutual, Lakeland, Florida

The study examines the role for and application of Systems Approaches to guard against plant pathogens by answering the following questions:

- 1) What role do Systems Approaches play in guarding against the introduction of plant pathogens into the United States?
- 2) What other approaches to guarding against the introduction of plant pathogens are used and are they more valid or reliable?
- 3) How is APHIS currently using Systems Approaches, why, and what can be done to make them better?
- 4) How does APHIS' use of Systems Approaches fit into the international safeguarding system?

The study had an operational focus with a scientific foundation and consisted of two components. The first component was an operational and scientific evaluation of APHIS' use of Systems Approaches for guarding against the introduction of plant pathogens into the United States. The second component consisted of a symposium to solicit input from the public and greater scientific community on the role for and application of Systems Approaches for plant pathogen exclusion. The National Plant Board hosted the symposium to provide an opportunity for interested stakeholders to review and comment on the first draft of the study and make recommendations for change as necessary.

The study is not designed to develop a Systems Approach program for a specific pest or commodity but determines the role for and application of Systems Approaches for plant pathogen exclusion. Evaluation of the risk assessment process used by USDA-APHIS-PPQ also is beyond the scope of this project. The study looks beyond narrow agendas of individual stakeholders to the overall efficacy of Systems Approaches for plant pathogen risk mitigation.



II. HISTORICAL PLANT PEST RISK MITIGATION PRACTICE

In the past, when quarantine pest risks were identified, it was customary for importing countries to rely on very highly effective chemical or other treatments to achieve what was called Probit 9 security. No other treatments or risk reduction methods were deemed necessary to achieve an acceptable level of protection.

Probit 9, a statistical standard requiring that 99.9968% of the quarantine pests in a commodity shipment be killed or sterilized by the requisite treatment, has been used by the United States for close to 50 years to define the required efficacy of quarantine treatments. In most cases, the target pests were insects, often exotic fruit flies. The standard was applied without consideration of other factors, such as infestation rates, effects of harvesting and processing methods, or shipping and storage conditions prior to marketing. The level of protection afforded by Probit 9 treatments was deemed adequate to prevent the establishment of quarantine insect pests. Even though several isolated insects might survive, the probability of fertile males and females surviving, mating, and finding suitable hosts for reproduction was extremely small.

A very different situation exists in the case of plant pathogens. A single infected/infested plant or plant part may give rise to hundreds, thousands or even millions of propagative units (propagules) of the pathogen, be they spores, bacterial cells, or viral particles. The germane questions then become:

- 1) Do host plants exist in the area into which an infected or infested commodity will be imported?
- 2) Do environmental conditions favor infection and disease development?
- 3) Can viable disease-causing propagules reach the host to initiate a new infection?

In the case of fungi, most spores can either be carried on air currents or in moving water. They may also move with the assistance of vectors, such as insects, machinery or humans. Bacterial cells may move with the assistance of wind driven rain or with vectors. Many viruses require insect vectors for transmission, although some are mechanically or nematode transmitted. Often, suitable vectors are already present in the destination area. Thus, protecting against the introduction or establishment of plant pathogens requires consideration of many questions, not simply whether a Probit 9 level of protection can be achieved.

Historically, plant pathogen introduction and establishment most often were managed by prohibiting the import of host materials (plants, fruits, seed, etc.) from regions of the world where the pathogen was known to occur. The spread of pathogens across geo-political boundaries has also been managed through the implementation of phytosanitary standards requiring commodities to be treated with highly effective chemical or temperature pest mitigation measures.

The case of citrus and mangos imported from Mexico, where the Mexican fruit fly (*Anastrepha ludens*) occurs, illustrates how the loss of a single pest mitigation treatment prompted the implementation of multiple, independent measures. At one time, Probit 9 security was achieved by treating the harvested fruits in a fumigation chamber using a prescribed dosage of ethylene dibromide applied according to a prescribed time, temperature and air circulation protocol. When ethylene dibromide use was cancelled in the 1980's, the Mexican government collaborated with citrus growers and the USDA to develop

and approve pest free areas in the State of Sonora. Additional alternative mitigation treatments were also implemented. In the case of mangos, hot water treatment further reduces risk of infestation, while on grapefruit grown in the southern Rio Grande Valley of Texas, methyl bromide fumigation has been used successfully.

The loss of a single effective mitigation measure is one event that would prompt plant protection agencies and stakeholders to consider implementing a Systems Approach. Loosening of trade restrictions also has been significant among several pressures leading to concerns that absolute prohibitions may be too restrictive. As a result, Systems Approaches implemented in the United States most often have succeeded earlier protective prohibition of imports as a risk reduction strategy in the trade of commodities.

In every instance to date, specific Systems Approaches have facilitated trade and concurrently thwarted the introduction and establishment of unwanted plant pathogens. Commodities imported under effective Systems Approaches are shown below in Table 1.

Table 1. Systems Approaches currently in place to guard against the introduction and establishment of plant pathogens in the U.S.

- Unshu oranges from Japan and Korea – initiated 1967.
- Plant growing in media – initiated 1980.
- Various fruit and ornamental trees from Europe – initiated 1980.
- *Rubus* from Europe – initiated 1980.
- Chrysanthemum plants from various countries – initiated 1980.
- Carnations from UK – initiated 1980.
- Grapevines from Canada – initiated 1992.
- Grafted lilac from Netherlands – initiated 1992.
- *Gladiolus* from Luxembourg or Spain – initiated 1992.
- Irish potato true seed – initiated 1995.
- Ya pears from China – initiated 1995.
- Citrus fruit from Argentina – initiated 2000. *

* The Systems Approach for Citrus fruit has been suspended following a decision issued in October 2001 by the U.S. District Court for the Eastern District of California. (Harlan Land Company, *et al*, vs. USDA, Case No. CV-F-00-6106-REC/LJO)

III. THE SYSTEMS APPROACH TO PLANT PEST RISK MITIGATION

As described earlier, the term Systems Approach is a relatively new phrase, but it actually describes a practice that has been followed for more than 30 years.

This study uses the definition of Systems Approach found in the Plant Protection Act [7 USC 7712 (e) Section 412 (e)] and described as:

“[A] defined set of phytosanitary procedures, at least two of which have an independent effect in mitigating pest risk associated with the movement of commodities.”

A May 2001 United Nations Food and Agriculture Organization, International Plant Protection Convention draft “International Standards for Phytosanitary Measures” (ISPM) dealing with the Systems Approach is entitled, “Integrated Measures for Pest Risk Management (Systems Approaches).” This draft document defines “System Approach” as:

“[T]he integration of different pest risk management measures, at least two of which act independently, and which cumulatively achieve the desired level of phytosanitary protection.”

While the definitions vary slightly and any number of measures may be included, the key point is that **at least two of the selected measures must have an independent *and* additive effect on reducing the risk of pest introduction**. Any other measures may be interdependent. If the success of one measure is influenced by the success or failure of another measure, neither is independent.

For example, sampling to determine if a pathogen is present and applying a pesticide if the pathogen is detected are not independent actions. If the sampling failed to detect an existing population, resulting in a decision not to apply the pesticide, both mitigation measures failed. On the other hand, two independent measures would be: 1) sampling to detect pathogen populations combined with 2) mandatory application of pesticide based on environmental conditions favoring infection.

In addition, there might be pest situations where multiple independent control measures would be incorporated to: 1) ensure effectiveness, 2) address some level of uncertainty associated with the efficacy of inter-dependent measures or a particular measure in the system, or 3) take into consideration unpredictable conditions or factors that could vary in such a way as to reduce the effectiveness of any single measure or the system as a whole (IPPC, 2000).

Another principle is equivalency. Equivalency recognizes that certain mitigation measures, while not identical, can have the same effect. This implies that the desired effect can be clearly defined and measured (quantitatively or qualitatively) and that there are various options that can be used to achieve the desired effect.

The Systems Approach, then, is the method of combining multiple independent measures to control quarantine pests in traded commodities. The use of multiple measures to control economically important pests and diseases associated with the *domestic production* of plants and plant crops is more commonly known as Integrated Pest Management, or IPM.

While the Systems Approach can be likened to an extended IPM program, there are important distinctions between the terms even though the basic approach may be the same. In either system, management strategies can be applied at any time from pre-plant selection or treatment of the growing area and selection of pest free planting material through growing season management, post-harvest handling and storage, and shipping to wholesale and retail outlets for distribution to the consumer.

An IPM program, on the one hand, is intended to actively monitor and control pests in the crop at a level sufficient to prevent or minimize economic damage, but does not ensure freedom from the pest in most cases. Systems Approaches, however, are specifically designed to ensure that a traded commodity will meet phytosanitary standards specified by the importing country.

Measures such as cold or heat treatment of harvested fruits, chemical treatments applied to growing crops, post-harvest fumigation, or controlled atmosphere storage of fruits can be used to kill certain quarantine pests. However, determining their efficacy in killing or rendering plant pathogens non-viable is critical and complex. Host resistance and pest free growing areas can play a significant role in the effort to exclude a pathogen from an export commodity. To prevent establishment of a quarantine pest in an importing country, commodities may be restricted for import during certain seasons and to limited destinations. For instance, tropical fruits might only be allowed to arrive in the northeastern United States and only in winter, where hosts are unavailable, or conditions are unfavorable for infection.



IV. APPLICATION OF THE SYSTEMS APPROACH TO PLANT PATHOGENS: THEORY AND PRACTICE

The concept and use of multiple management practices to guard against the introduction of plant pathogens and other food-borne pests has been in use since the 1960's (IPPC, 1999; Jang and Moffitt, 1994). The protocol required to export Unshu oranges from Japan to the U.S. is a well-known example of a Systems Approach that has been in use for more than 30 years.

Several others examples of active, successful Systems Approaches exist. The United States' importation of various fruit and ornamental trees from Europe, chrysanthemums from various countries, and carnations from the United Kingdom are all regulated by Systems Approach protocols initiated in 1980. In 2000, a Systems Approach was approved for the importation of citrus fruit from Argentina.

Appendix A (beginning on page 31) presents case studies of six very different Systems Approaches. These studies are listed below:

- 1) True potato seed from Chile's 'X' region: Managing multiple viral pathogens
- 2) European stone fruit yellows phytoplasma: Certified nurseries in six nations – Belgium, Canada, France, Germany, Great Britain, and The Netherlands
- 3) Brown rot of stone fruit caused by the fungal pathogen *Monilinia fructigena* honey: Government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands
- 4) Stone fruit and plum pox virus: government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands
- 5) White rust of chrysanthemums caused by the fungal pathogen *Puccinia horiana*: Europe, East Asia, and specific South American countries
- 6) Citrus from Japan and Korea (Unshu Oranges) and Argentina
 - a) Citrus canker caused by the bacterial pathogen *Xanthomonas campestris* pv. *citri*
 - b) Citrus black spot caused by *Guignardia citricarpa*
 - c) Citrus scab caused by multiple fungal pathogens
 - d) Integration of measures for three diseases: Citrus canker, citrus black spot, and citrus scab

The goal of any nation's phytosanitary import regulations is to prevent entry *and* establishment of exotic or non-indigenous organisms, including plant pathogens that pose a risk to plant life or health. To date, no APHIS-PPQ-approved Systems Approach to safeguard against introduction and establishment of plant pathogens has failed. (Burnett, 2001).

Either entry or establishment must be prevented. So, an effective Systems Approach may employ independent mitigation measures targeting either or both entry *and* establishment. If a commodity is to be imported and distributed in areas where conditions are suitable for establishment of a targeted

pathogen, mitigation measures providing a high degree of confidence that a targeted pathogen would be detected and eliminated at origin would be most favorable.

If, however, distribution of an imported commodity were limited to those areas where neither the commodity nor suitable hosts for the targeted pathogen are found, it would, therefore, be less critical to detect and eliminate the pathogen before entry of the commodity. This presumes that the commodity will not be trans-shipped to areas where host material is present.

The focus of the Systems Approach, as with other risk mitigation measures, is to reduce the probability of entry or establishment of a targeted pest to an acceptable level. As described earlier, the Systems Approaches overseen by APHIS share a similar design and implementation to integrated pest management (IPM) (defined on page 6) programs used for pest management in crops. In an IPM program for crop-specific plant pathogens, the grower implements a series of mitigation practices known as IPM elements, which, in combination, minimize risks associated with the plant pathogen. The IPM technique also has application to insect and weed pest management as well. IPM labeling of produce requires that a number of prescribed IPM elements be adopted in that production system. See details at the following web site: <http://www.nysipm.cornell.edu/elements/AboutEl.html>. The catalog of IPM elements represents a range of crop-specific and agro-eco-region-specific practices intended to mitigate the risk of an unacceptable pest management outcome. Common elements include pest resistant crop varieties, crop rotation, cultural practices, biological controls, physical barriers to pest infestation, and/or chemical methods.

An effective IPM system conjoins basic, implementation and maintenance research with stakeholder input to identify effective and manageable elements in the system. Stakeholder participation in the development of an effective Systems Approach for imported and exported agricultural products is critical. (See page 26, Summary of **Systems Engineering**.) The goal is risk mitigation, which is accomplished by designing systems with the appropriate suite of IPM or pest risk mitigation elements.

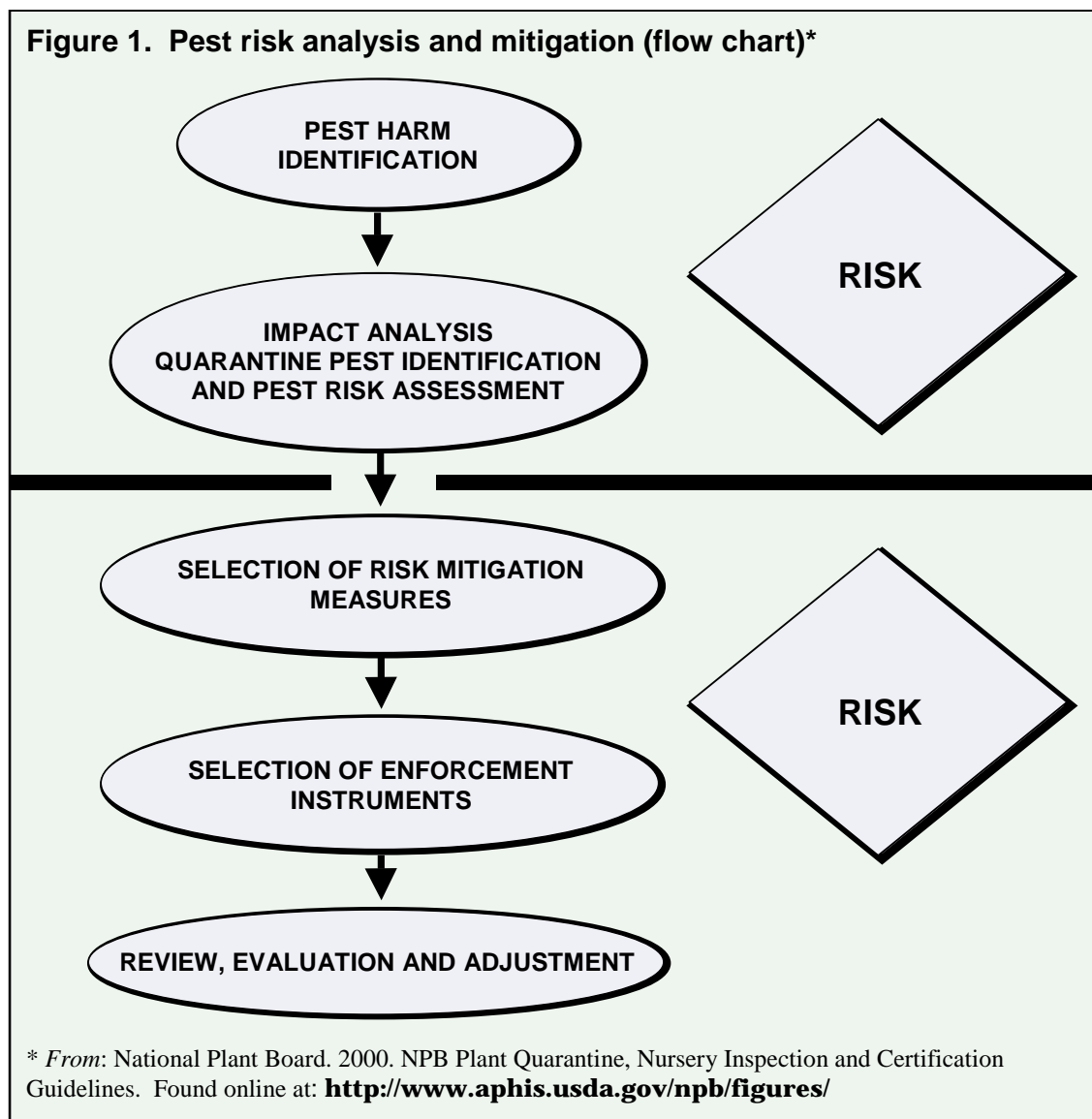
In a Systems Approach, as with an IPM approach, two or more *independent* control or mitigation measures are required. If only one measure is required, and it fails, the pathogen gains entry. If multiple independent mitigation measures are used, they form a pyramid, each measure building on the prior measures and increasing the probability of preventing the entrance and establishment of an unwanted pathogen.

This is an approach that is used in many aspects of life. Consider a home security system. If our goal is to prevent a burglar from taking our most valuable household possessions, several deterrents might be employed. Doors and windows are locked. Should the thief gain entry, though, there's a big, loud dog in the house. Perhaps the watchdog is placated with a biscuit. Now, the burglar finds that our valuables are in a combination-locked safe. Each measure employed represents a barrier between the burglar and our possessions, and as such increases the probability that our valuables won't be pilfered.

In a Systems Approach, while each of the elements employed mitigates the risk of a pest introduction, they cannot eliminate it. This is true irrespective of the suite of pest mitigating elements deployed. Simply stated, there is no such thing as "zero risk." So long as human enterprise and trade continue, no individual control measure can be guaranteed to be 100% effective. Risk mitigation efforts, for instance, rarely address the introduction of a targeted pest that might result from smuggling.

In designing a specific Systems Approach, a team approach involving the participation of scientific specialists and stakeholders should be employed from the beginning of its design through its implementation, and during maintenance and enforcement. (The Systems Engineering section of this report explains how the systems engineering process is utilized to develop complex systems like Systems Approaches.)

Such a team would first conduct a risk analysis quantifying the likelihood of introduction AND establishment and the potential harm a pest or group of pests could cause. Once these risks have been assessed, the team would then identify and evaluate the effectiveness of the elements or measures that could be used to reduce the risk of establishment of a plant pathogen to an acceptable level. The general steps in the risk analysis process, selection of mitigation measures and enforcement process, are displayed in Figure 1.



Any importing nation must determine the acceptable probability level of excluding a specific pathogen. Mitigation measures can then be evaluated to determine if they provide the required probability level. Some phytosanitary measures, such as methyl bromide fumigation, are one-step mitigation measures. Scientific data and years of experience have shown that this treatment can provide an acceptable level of protection for certain commodity/pest combinations. Unfortunately, certain commodities are damaged by chemical fumigants. Therefore, alternative mitigation strategies are needed to allow their exchange.

Two general approaches can be taken to evaluate the risk mitigation elements or measures. The team of discipline experts and stakeholders discusses available measures and, through a process of expert opinion or quantitative research data, assigns either qualitative or quantitative scores for the performance of a particular measure. In theory, the probability of protection provided can be quantified and a product of the sequence of risk mitigating measures determined. While the theory underlying this quantitative approach is sound (as described in **Appendix B**), data are often lacking on the myriad combination of mitigating elements. In practice the qualitative approach has proven effective and often arises from a combination of research data and expert opinion. An excellent example of a qualitative assessment is that which was applied to assess mitigation measures available for pests and pathogens associated with Russian timber imported to the United States.

In that assessment the team scored a series of mitigation measures as *effective*, *not effective*, or *requires research*. Those measures included methyl bromide, kiln drying, steam heat, irradiation and debarking (Table 2). In addition to these measures, other elements were included to further reduce the risk of introduction such as requiring that only apparently pest- and disease-free logs be imported.

Table 2. Efficacy of mitigation measures available for pests and pathogens associated with Russian timber imported to the United States^a

| Pest/Location | Methyl bromide | Kiln drying | Steam heat | Irradiation | Debarking |
|--|----------------|-------------|------------|-------------|-----------|
| Pests on the outer surface | | | | | |
| Aphids/wooly adelgids/Siberian silk moth | E | E | E | R | E |
| Asian gypsy moth/nun moth | E | E | E | R | E |
| Root/stump insects | E | E | E | E | E |
| Scale insects | E | E | E | R | E |
| Flat bugs | E | E | E | R | E |
| Pathogens | R | E | E | R | E |
| Pests in or under bark | | | | | |
| Engraver beetles/weevils | E | E | E | R | E |
| Pests in the wood | | | | | |
| <i>Monochamus</i> , <i>Xylotrechus</i> | E | E | E | N | N |
| Siricidae | E | E | E | N | N |
| Pathogens | R | E | E | N | N |
| Wood nematodes | R | E | E | N | N |

LEGEND: E = Effective, N = Not effective, R = Requires research

^a USDA, Forest Service. Pest Risk Assessment of the Importation of Larch from Siberia and the Soviet Far East. Misc. Pub. 1495, Sept. 1991. (Draft Version)

Qualitative methods such as above are the most frequently used technique by APHIS to generate pest risk mitigation assessments. The practice of assembling a sequence of mitigating elements is based on both the theory and the empirical evidence that any single measure may not be effective at mitigating risk. Table 3 compares the probability of successful detection/elimination of a plant pathogen using a single mitigation measure with the success that can be achieved using multiple mitigation measures as in the Systems Approach. The example shown is based on introduction of a pathogen prior to the implementation of the first mitigation measure in the additive sequence as shown in the fourth and fifth columns of the table. The calculation would be similar, though, no matter what point in the production and shipment cycle the target pathogen is presumed to infest the commodity.

Table 3 illustrates these strengths of the Systems Approach:

The use of certified propagation materials (mitigation measure #1) has a probability of successfully eliminating the hypothetical plant pathogen of 0.90, meaning the probability of the pathogen being introduced by a failure of the certified propagation material component is 0.10. If this were the only mitigation measure, the probability of failure is 0.10.

Used alone, mitigation measure #2 (in-field chemical application) has a theoretical probability of success of 0.80. Mitigation measures #1 and #2 are independent of each other. Used together, the probability of successful elimination due to measure #2 is applied to the 0.10 failure following the first mitigation measure. The resulting probability of successfully eliminating the pathogen would be 0.08 ($0.80 \times 0.10 = 0.08$). Adding this 0.08 to the 0.90 eliminated by measure #1 results in a probability of successfully eliminating the pathogen of $0.90 + 0.08 = 0.98$ if both measure #1 and measure #2 are used. This example assumes the pathogen is exposed to each of the mitigating elements. In the event a pathogen enters the system after several mitigating elements have been applied, then mitigating elements preceding the entry point would have no effect on the probability of successful elimination.

Using two measures clearly provides a greater degree of safety than using either measure alone. Each additional independent mitigation measure increases the probability of successfully detecting and eliminating the target pathogens.

Table 3 shows the increasing probability of successful pathogen detection or elimination as each additional measure is applied. This multi-step approach clearly provides an increasing level of security as compared to single mitigation approaches. In order for a pathogen to enter and become established, the commodity being imported would have to be infected AND all mitigation measures would have to fail. The probability of this happening is reduced with each additional independent mitigation measure incorporated into the management system.

In the hypothetical example given in Table 3, after the application of the six mitigation measures, the probability of the hypothetical pathogen entering and becoming established is 0.0000003. Is this an absolute guarantee that the system won't fail? No! Only that the probability of failure is extremely low. No absolute guarantee is possible.

Table 3. Comparison of the probability of successful detection/elimination of plant pathogens using a single mitigation measure versus multiple independent mitigation measures (Systems Approach).

| Hypothetical Mitigation Measure | Single Component | | Cumulative Systems Approach | |
|---|--|--|---|--|
| | Probability of Successful Elimination or Detection | Probability of Failed Elimination or Detection | Cumulative Successful Elimination or Detection | Cumulative Failed Elimination or Detection |
| 1 Certified Propagation Materials | 0.90 | 0.10 | 0.90 | 0.10 |
| 2 In-field Chemical Application | 0.80 | 0.20 | $0.90 + (0.80 \times 0.10) = 0.98$ | $0.20 \times 0.10 = 0.02$ |
| 3 Pre-harvest Sample and Incubation to Detect Latent Infections | 0.85 | 0.15 | $0.98 + (0.85 \times 0.02) = 0.997$ | $0.15 \times 0.02 = 0.003$ |
| 4 Post-harvest surface sterilization in the pack house | 0.90 | 0.10 | $0.997 + (0.90 \times 0.003) = 0.9997$ | $0.10 \times .003 = 0.0003$ |
| 5 Port of Entry Inspection | 0.95 | 0.05 | $0.9997 + (0.95 \times 0.0003) = 0.999985$ | $0.05 \times .0003 = 0.000015$ |
| 6 Restricted Distribution to Areas Unsited for Pathogen Establishment | 0.98 | 0.02 | $0.999985 + (0.98 \times 0.000015) = 0.9999997$ | $0.02 \times 0.000015 = 0.0000003$ |

This example is for a series of sequential mitigation measures. The additive effects are sequence-specific with each succeeding mitigation effect being a probability conditional upon the preceding mitigation effect(s). Other examples of Systems Approaches have simultaneous action of independent measures.

V. DESIGNING A SYSTEMS APPROACH

Data and Knowledge Base Requirements

Generally, Systems Approaches will be more difficult to develop and implement than a Probit 9 post-harvest treatment. The degree of difficulty largely will depend upon how much biological, risk mitigation, and other information is already known. Since the dynamics of any crop/pest complex are shaped by the biology of the crop (host) and related biological complex, its soil climate regime (agro-eco-region) and local agronomic practices, each specific Systems Approach for a crop/pest complex must be a unique assemblage of tactics. In the best case, a specific Systems Approach would have comparatively fewer negative impacts on commodity quality, or allow for speedier and, therefore, more cost-effective trade than alternative risk mitigation measures.

A joint workshop of USDA-ARS and USDA-APHIS identified the conditions that allow for a successful Systems Approach to be developed (Liquido, *et al*, 1997):

- Pest(s) associated with the commodity are known;
- Basic biology of the pest(s) is known, including pest/host relationship, dispersal, alternate hosts, habitat selection, and population dynamics,
- Knowledge of the pathogen and disease life cycle;
- Systems exist for field surveillance and/or detection of pest(s) in shipment,
- Knowledge of harvesting, packing, and marketing practices exists;
- Pest(s) are generally absent or rare in commercial commodity because of:
 - Normal field management,
 - Poor host,
 - Resistant cultivar,
 - Phenological asynchrony between pest and commodity, or
 - Ecological limitation-based rarity of pest in growing area.
- No alternative method is available for obtaining phytosanitary security, or a Systems Approach is more desirable because it does not damage the commodity and/or is more cost-effective,
- Sufficient volume of the commodity is shipped to justify and offset the program costs,
- Some degree of redundancy and independence between program components can be designed to allow for variability in pest populations or partial failure of other components, and
- Phytosanitary security is apparent either by qualitative or quantitative assessment.

The development of a Systems Approach must be undertaken in a methodical manner, making the best use of the knowledge of the pathogen and host biology, pathogen ecological requirements, the marketing and distribution system, and the level of risk acceptable to the importing country. It is important to realize that a control measure must be both effective and practical. Systems Approaches have been developed for both propagative plant material and for plant products (fresh fruit). A two-year post-entry quarantine might be both effective and reasonable to guard against viruses in fruit trees, but would clearly not be acceptable for a perishable commodity.

The International Plant Protection Convention (IPPC) developed a set of steps to be taken to develop and implement a Systems Approach (IPPC, 2000):

- Identify the pest risk, pathway risk;
- Describe the pathway;
- Identify where management measures occur or can be applied;
- Distinguish essential measures and other factors or conditions;
- Identify independent and dependent measures and redundancy;
- Assess the individual and integrated efficacy of essential measures;
- Assess feasibility and trade restriction impact;
- Consult and negotiate with importing country;
- Implement with documentation and reporting; and
- Review and modify as necessary.

Components of a Systems Approach

The components available for inclusion in a Systems Approach run the entire gamut of pathogen management, but can generally be divided into four categories:

- Exclusion of the pathogen;
- Detection of the pathogen; (detection alone is not a management or risk mitigation measure), and
- Elimination of detected pathogen populations, or
- Risk reduction of establishment in the importing region.

Available Risk Management Options

Regardless of how the mitigation measures are categorized, they can be applied at pre-harvest, harvest, post-harvest, and during shipping and distribution.

Pre-harvest

- Field certification/management (treatments, biocontrol, etc.),
- Protected conditions (glasshouse, fruit bagging, etc.),
- Resistant or less susceptible cultivars,
- Harvesting plants at certain age or time of year,
- Vector mating disruption (particularly effective with insects),
- Cultural controls,
- Vector- and pathogen-free areas, places or sites of production,
- Low prevalence (continuous or at specific times), and
- Testing and subsequent elimination of infected components.

Harvest

- Culling, inspection or selection,
- Stage of ripeness/maturity,
- Timing of harvest,
- Sanitation (e.g., removal of reservoir hosts, “trash”), and
- Harvest technique and handling.

Post-harvest treatment and handling

- Treatment to kill, sterilize or remove vectors or pathogens (fumigation, irradiation, cold, controlled atmospheres, washing, brushing, waxing, dipping, heat, etc.),
- Inspection and grading,
- Sanitation, including removal of parts of the host,
- Certification of packing facilities, and
- Testing with subsequent elimination of infected component.

Shipping and distribution

- In-transit or on-arrival treatment or processing,
- Restrictions on end use, distribution and periods, and ports of entry restrictions,
- Post-entry quarantine,
- Inspection and/or testing with subsequent elimination/denial of entry,
- Speed and type of transport, and
- Sanitation (freedom from contamination of carriers).

Minimum criteria for a measure to be considered a required component in a Systems Approach are that the measure: 1) is clearly defined, 2) is found or known to have a specific level of efficacy, 3) is officially required (mandatory), and 4) can be overseen and controlled by the responsible National Plant Protection Organization (NPPO). (IPPC, 2000.)

The IPPC further describes three structural approaches that can be used as the framework for a Systems Approach:

Mitigation Systems – a combination of official phytosanitary procedures.

Quality Systems – a mix of phytosanitary procedures and other procedures.

Typically, these include a range of processes designed to ensure the quality of commodities, but also contribute to phytosanitary security.

Control Point Systems – equivalent of the Hazard Analysis Critical Control Point (HACCP) used in food safety. This involves rigidly defined independent events or processes that are measured, monitored, and controlled.

VI. ASSESSING SYSTEMS APPROACH PERFORMANCE: VERIFICATION

In the end, the success of the Systems Approach will be measured by its ability to achieve a defined level of phytosanitary security. Phytosanitary security results from the application of single phytosanitary measures in a specific situation and may be evaluated quantitatively or qualitatively according to the defined endpoint.

Single tactic disinfestation treatments as a rule overkill significantly so as to ensure that the probability of a target pest surviving is very low. For example, methyl bromide fumigation may provide insect kill rates of 99.9968% (Probit 9) of treated individuals. While Probit 9 provides a standard for the evaluation of a single treatment as a risk mitigation method, new measures are needed for assessing the performance of particular Systems Approaches. Under current international phytosanitary agreements, an importing country will determine what constitutes adequate quarantine security, provided those security levels it sets which exceed typical standards are justified by sound risk assessment. In practice, the exporting country develops the Systems Approach for a particular quarantine pathogen(s) and then proposes it to the importing country. The result is a negotiated level of quarantine security, which could be lower than, higher than, or equal to Probit 9.

Such negotiations can only take place when the qualitative or quantitative degree to which the particular measures making up the Systems Approach are known or can be calculated. The same is true in terms of performance assessment or verification (compliance determination) by the importing country.

Interventions in a well-designed Systems Approach should be additive or synergistic. For example, systems are comprised of control tactics with an associated efficacy and by events that can lead to infestation. Those events may include orchard floor conditions, fruit falling to the ground, or condition of the packing area (i.e., pest free for some period of time). Probabilities of infestation can be calculated for each of these events or possible points of infection by a pathogen.

As a specific case example, a chemical treatment for the avocado seed weevil will have an associated efficacy. The probability of a pest complex infesting an avocado is increased when the fruit has fallen to the ground. In the case of avocado, the mortality resulting from a combination of treatments was estimated by multiplying the effects of individual treatments (Finney, 1971; Couey and Chew, 1986; Robertson and Preisler, 1992; and reviewed in Mangan and Sharp, 1994).

The expected mortality (M) of a target pathogen following the application of a series of treatments $[(t_1, t_2, t_3 \dots t_k)]$ where t_k is the rate at which the treatment eliminates the pathogen, and k represents the number of treatments; and where $(1-t_k)$ is the rate at which the pathogen survives the treatment] is calculated as follows:

$$M = 1 - (1 - t_1)(1 - t_2)(1 - t_3) \dots (1 - t_k)$$

Any number of treatments could be included in this approach. This expected mortality would then be compared to experimentally derived measures of mortality to evaluate the additive effects of combined treatments.

Inasmuch as a Systems Approach involves both treatments and events in the management of risk, a probabilistic method may be applied. Treatments can be evaluated and assigned a probability to reduce potential pest risk. Similarly, the probability to reduce potential pest risk can be estimated or measured for the effectiveness of field sanitation, host resistance, post-harvest safeguards, etc. The reality is that there is variation associated with any of these measures, and for this reason, a range of values is often reported and used in such analyses.

Once the necessary risk reduction matrix is constructed, the probability that phytosanitary security will be achieved can be estimated (under a range of assumptions, i.e., best case, worst case) in a fashion similar to that described above. The probability that a Systems Approach provides an agreed upon level of phytosanitary security can be estimated using the following equation [where P_{SA} is the probability that the target pathogen will be detected or eliminated; N represents the number of treatments or events; and $(1-P_N)$ is the probability of an independent mitigation measure failing to detect and eliminate the pathogen]:

$$P_{SA} = 1 - (1-P_1)(1-P_2)\dots(1-P_N)$$

Take the hypothetical mitigation measure presented in Table 3 as a case in point. The probability that the first three elements successfully detect/eliminate the pathogen (i.e., certified propagation of materials, in-field chemical application, and pre-harvest sampling to detect latent infections) was determined by subtracting the product of the probability that each of these elements would fail from one $[1 - (0.1)(0.2)(0.15)]$, which returns a cumulative probability of successful detection or elimination of 0.997. This example illustrates two key concepts supporting the utility of a Systems Approach.

First, even in a worst case scenario where the rate of successful detection or elimination assigned the mitigation measure in which there is most confidence turns out to have a real value of zero, the net probability of detection or elimination only drops to 0.97 $[1 - (1)(0.2)(0.15)]$. Also, note that, when an additional independent mitigation measure is added into the suite of measures, the probability of failure (shown in the third column of Table 3) becomes a multiplier in the equation above. For instance, if post-harvest surface sterilization in the packinghouse (Measure 4 in Table 3) is added to the three measures listed, the probability of successful detection and elimination now equals $[1 - (.1)(.2)(.15)(.1)]$, or 0.9997.

VII. ALTERNATIVE PEST RISK MITIGATION METHODS

Numerous alternative pest risk mitigation methods are available for integration as components of a Systems Approach. Some alternatives can also serve as “stand alone” measures, depending primarily on the desired level of quarantine security. In general, these “stand alone” alternatives are most useful in situations where there is only one pathogen or disease of concern. Where two or more pathogens/diseases of concern occur, multiple measures will often be required to achieve the specified level of quarantine security.

Examples of some alternative pest risk mitigation methods follow:

Pest Free Area

More commonly used when the primary concern is insect pests, this concept has also been employed for plant diseases. These areas are covered by quarantines or other appropriate exclusion measures to prevent entry and establishment of the targeted quarantine pathogen. Freedom from the pathogen has been and continues to be verified by ongoing surveys. Pest free areas may be large geographic areas or small production facilities such as greenhouses. The key is the ability to ensure that they are and remain pathogen free.

Examples include:

- Argentine citrus fruit moving from citrus canker-free states to the United States,
- Florida citrus fruit moving from citrus canker-free production areas to other citrus-producing states,
- South African citrus fruit moving from black spot-free production areas to the United States,
- Australian citrus fruit moving from black spot-free production areas to the United States, and
- The Mexicali Valley of northern Mexico designated as a Karnal bunt-free area, allowing the export of wheat without restriction.

Varietal Resistance

Certain varieties of a given commodity may be resistant, very highly resistant, or even immune to infection by a quarantine pathogen, and could be allowed movement on that basis. As an example, certain varieties of ornamental barberries are resistant to infection by *Puccinia graminis* (black stem rust of wheat). Barberry is the alternate (aecial) host of this rust and is prohibited in some United States locations by federal domestic quarantine. Recognition of the highly resistant status of certain barberry varieties in recent years has allowed them to be planted in areas of the United States where, historically, they were prohibited.

Commodity Treatment

Various commodity treatments are recognized as eradicated for certain pathogens of quarantine concern. For example, hot water dips of dormant grape cuttings for precise times at carefully controlled

temperatures are known to kill the phytoplasma that causes flarescence doree and the bacterium (*Xylella fastidiosa*) that causes Pierce's disease. These treatments may also be used to eliminate nematodes from certain bare-root plants.

Tissue Culture

Tissue culture alone is not a pest risk mitigation measure. However, if the original plant material is tested and confirmed to be free of the quarantine pathogen, tissue culture allows the rapid multiplication and low risk movement of plant material in an aseptic environment. If parent stocks are periodically tested and subsequent production occurs under conditions that ensure pathogen exclusion, tissue culture will prevent the artificial spread of quarantine pathogens.

Commercial Part of Commodity Free of Quarantine Pathogen

Not all plant parts are infected by certain pathogens, enabling movement of uninfected parts even when the disease of concern is known to occur in the production area. As an example, *Xylella fastidiosa*, the causal agent of Pierce's disease of grapes, does not infect the fruit. Therefore, grapes can be moved with a high level of quarantine security from a Pierce's disease-infested area to one that is not infested.

Arguably, the best-known example is the movement of many different types of seeds. Even though pathogens of quarantine concern may infect the parent plants, most do not infect the seed.

Growing Season Disease Control

Use of effective growing season treatments, such as chemical sprays, can prevent infection/infestation of a crop. Inspection prior to harvest and shipping is used to confirm freedom from infection. As an example, chrysanthemums are produced in greenhouses in Columbia utilizing a carefully timed spray program to control chrysanthemum white rust, which occurs in the production area. The plants are carefully inspected prior to harvest and shipping to ensure freedom from the disease.

Limited, Regional Marketing of Commodities

Usually coupled with other control measures, limiting the region(s) of the country where a commodity may be marketed can provide adequate assurance that a disease/pathogen of concern will not be introduced into areas of the United States where the commodity is grown. As an example, several years ago Florida citrus fruit coming from areas where there was uncertainty regarding freedom from citrus canker was limited to sales in the northeastern states, well away from other citrus-producing states in the United States.

VIII. SYSTEMS ENGINEERING

The Systems Approach to safeguarding against plant pathogens is scientifically sound, accepted by the international trade community, and has been successfully implemented in the past. The challenge is to build confidence in its efficacy. The primary limitations and concerns that were uncovered during the study had to do, not with the concept and principles of the Systems Approach, but with the process employed by APHIS in developing and implementing a specific Systems Approach. Particularly, the areas of concern included 1) customer involvement, 2) implementation of an approved Systems Approach protocol for a specific crop/exporting nation combination, and 3) ongoing monitoring of the implementation of the protocol.

The science and practice of “Systems Engineering” has been used by the aerospace industry, the Department of Defense, NASA, the USDA, and other organizations to address concerns such as those uncovered by the study team (Kayhanian and Martin, 1994; Keizur and Mar, 1994; Lee, *et al*, 1994; Mackey and Mackey, 1994; Schneider, *et al*, 1994; Terry, 1994; Walters, 1994; Wymore, *et al*, 1994). Systems Engineering is described by the International Council on Systems Engineering as “the discipline of developing and engineering complex systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting these requirements, then proceeding with design synthesis and system validation while considering the complete problem.

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured design process that proceeds from concept to production to operation in an orderly fashion. (<http://www.incose.org/whatis.html>). In lay terms, Systems Engineering is the bridge between solutions now available through advancements in science and technology and the needs of the customer.

The life cycle of any system can be divided into seven major stages (Wymore, 1994):

- 1) Requirements Development,
- 2) Concept Development,
- 3) Full-scale Engineering,
- 4) System Development,
- 5) System Test,
- 6) System Operation, and
- 7) Retirement and Replacement.

Requirements Development

The first step in the highly important Requirements Development stage of the process is Problem Definition – stating the problem as the CUSTOMER sees it. Scientists often have the tendency to define the problem as a technical problem that is best solved by research interests.

For example, the customers’ problem might be defined as wanting to have access to imported fruits and vegetables, while at the same time wanting to insure the health (economically, biologically, and environmentally) of American agriculture. A crop management scientist might define the problem as

“How can a crop be protected from infection by certain plant diseases while it is still in the field in the exporting country?” A post-harvest plant pathologist might define the problem as “How can any pathogens present on the fruit or vegetable be killed or rendered non-viable prior to its shipment to the U.S.?” A PPQ inspector might define the problem as “How can inspectors reliably detect any pathogens present when the produce arrives at the port of entry?” Obviously, each of these questions represents a subset of the overall customer problem, and would, unintentionally, eliminate other aspects of the problem, and potential solutions, from consideration.

It is critical that the “human problem,” rather than the technical problem, be clearly defined, in order to ensure that no feasible solutions are overlooked, and that all valid concerns are addressed. In order to define the problem from the customers’ viewpoint, the customers must be identified. In the case of Systems Approaches for safeguarding against plant pathogens, the customer groups might include U.S. growers, commodity groups, and processors; U.S. consumers; action agencies at the federal, state, and local levels; policy makers; our trade partners; growers in the exporting countries; and others.

Input from each customer group, although potentially conflicting, should be considered when developing the problem definition. Adequate participation from the various customer groups in defining the problem provides “buy-in” and increases the likelihood that the customers will accept the eventual solution to the problem. If the problem is not clearly defined, there is a risk that the wrong problem will get solved!

After the customer groups have been identified, and customer input is used to clearly define the human problem, the next step is to clearly state, and document, the Performance Requirements. How well must the solution perform? How accurately? How efficiently? How reliably? An example of overall system performance requirement is given in Figure 2.

Figure 2. Example of an overall performance requirement

| Overall Performance | |
|---------------------------------|------------|
| System Operation | 30% |
| Efficacy of Safeguarding | 55% |
| World Trade Issues | 15% |

As a weighting factor, each contributing criterion is assigned a percentage that indicates its relative importance. In this hypothetical example, “System Operation” is designated as twice as important as “World Trade Issues.” Each of these criteria can be further subdivided until each criterion is a specific, measurable requirement. A further subdivision of the System Operation criterion is given in Figure 3.

Figure 3. Example of further subdivision of the system operation criterion

| System Operation | |
|-----------------------------|------------|
| Capacity | 15% |
| Time Delay | 15% |
| Flexibility | 10% |
| Unaddressed Problems | 15% |
| Availability | 15% |
| Reliability | 15% |
| Maintainability | 15% |

In this example, criteria such as the capacity of the system, the flexibility of the system to adjust to new situations, and the reliability of the system are specified and given weights. Specific measurements under these criteria might include the number of produce cartons that can be processed per hour or number of working hours lost due to malfunction of the system.

After the Performance Requirements are identified and documented, the next step is to identify the Technology Requirements. This includes documentation of what technologies and information are AVAILABLE to develop the system, MUST BE USED, and CANNOT BE USED. Examples might include a specific agency standard software suite or the “buy American” requirement of many federal contracts. Performance requirements address the equipment and hardware, software, and bio-ware to be considered in developing a solution to the problem.

The next section is specification of the Utilization of Resources. This includes how much can be spent on acquisition of the solution and on operation and maintenance, as well as the allowable economic, environmental, and social impacts of any potential solution.

The final step in the Requirements Development stage is to specify the System Test Requirements. This step responds to the questions: How will the implemented solution be tested for acceptable performance? What range of inputs will be used to test the solution? The System Test might require that the solution be tested under both weather conditions that favor the development of plant diseases and weather conditions that do not favor disease development. The System Test will specify the conditions under which the solution will be tested and exactly what measurements and evaluations will be made.

All the requirements discussed above are specified before any solution is developed. This allows the solution developers to know before beginning to select a solution, what level of performance must be achieved, what technologies are available or forbidden, what resources can be used, and how the system will be tested prior to final acceptance. Customer input and highly detailed,

rigorously documented requirements increase the probability that the final solution will be acceptable.

Concept Development

This stage considers all solutions not eliminated by the criteria specified in the Requirements Development stage. If a seemingly bizarre solution cannot be eliminated by the documented criteria, it is likely that there are requirements that have not yet been stated. Thus, straw systems that meet all current requirements – and, yet are unacceptable to one or more customer groups – can be used to identify unspoken requirements and to uncover hidden agendas. Examples of the range of potential solutions where the goal is to safeguard against the introduction and establishment of plant pathogens and, yet, provide access to imported plant products include:

- Prohibit all imports (likely to be eliminated by trade requirements).
- Allow all imports (likely to be eliminated by requirements to protect U.S. agriculture).
- Allow all imports after fumigation with methyl bromide (some produce is easily damaged by methyl bromide, so this solution would be weak with respect to requirements addressing product quality).
- Visually inspect each individual piece of fruit or vegetable (would probably not meet requirements for prompt processing of imports in order to minimize degradation of product quality and shelf life).
- Develop and implement high-tech sensing system (technology might not be available).
- Use a combination of pest management strategies, monitoring, and inspection to select appropriate commodity shipments for import (has potential to be designed carefully enough to address the probable requirements).

The Concept Development stage is the brainstorming step. After identifying the range of potentially acceptable solutions, a short list of the most promising concepts is generated. The most promising concepts are then evaluated in more detail, by estimating the expected performance of each concept within a range of scenarios that might include the worst case, the best case, the most common case, etc. This might be done qualitatively by a panel of experts or quantitatively by developing detailed mathematical models. The rigor with which this evaluation is done is determined, in large part, by the resources available for this step.

A weighting factor can be assigned to each scenario depending on its perceived importance. The expected performance of each concept under each scenario with respect to each of the Performance Criteria is estimated. An overall performance score based on the summation of the performance under each scenario for each individual criterion multiplied by its weighting factor is calculated for each concept. A trade study is conducted to weigh the performance and cost for each of the promising concepts (Table 4).

Table 4. Hypothetical trade study

| | Performance Score | Cost |
|-----------|-------------------|----------|
| Concept A | 0.55 | \$10,000 |
| Concept B | 0.80 | \$20,000 |
| Concept C | 0.85 | \$60,000 |

What is the tradeoff between performance and cost? Is the increase in performance between concept A and concept B worth the additional cost? Concept C has the best performance score, but is significantly more costly. Are the resources that would be required available? Once the trade study is completed and the most acceptable concept identified, it must be screened to ensure that the choice makes sense intuitively, technically, regulatorily, politically, and economically.

Full-Scale Design

This is the stage during which the detailed design of the solution is conducted. The “build-to” specifications are developed and documented. Additional specifications might address “hire-to” standards, training, database, operational, and monitoring specifications. All the details that are necessary to ensure the solution will perform as designed must be clearly documented.

System Development

The System Development stage builds and installs the equipment and hardware, hires and trains the personnel, creates the necessary databases, etc.; all in accordance with the details specified in the Full-scale Design.

System Test

After the solution is fully developed, it is subjected to the System Test Protocol that was developed during the Requirements Development step. Any problems developed during the System Test must be addressed to ensure the solution performs as required. Modifications might be necessary to improve performance to an acceptable level.

System Operation

Once the solution has passed the System Test, the System Operation stage begins. This stage requires that the approved solution be implemented in accordance with the detailed design. The ongoing performance of the solution must be monitored and the implemented system refined and upgraded as needed. A perfect solution can fail if it is not properly implemented and monitored.

Retirement and Replacement

Finally, the solution enters the final stage: Retirement and Replacement. Plans must be in place to monitor the implemented solution to determine when technologies, information, or needs have changed sufficiently that the existing system is no longer the best solution and a new solution should be put in place.

In summary, Systems Engineering provides a method to:

- 1) Clearly define the problem from the customer's viewpoint;
- 2) Identify requirements from multiple and, sometimes, conflicting customer groups;
- 3) Design conceptual solutions that meet the customers' requirements;
- 4) Evaluate the potential solutions and select the solutions with the highest probability of success and acceptance;
- 5) Develop and implement the most promising concept; monitor the ongoing performance and improvement of the solution; and
- 6) When appropriate, retire the system.

A methodology such as Systems Engineering can be used to improve the process of developing new Systems Approaches for guarding against the introduction of plant pathogens.



IX. CONCLUSIONS

This study of the Systems Approach was mandated by the U.S. Congress at the behest of agricultural commodity groups. The definition of the Systems Approach used in this report is that found in the Plant Protection Act “a defined set of phytosanitary procedures, at least two of which have an independent effect in mitigating pest risk associated with movement of commodities.” While Congress specified that this report deal with imports of plants or plant products into the United States, much of what is reported here is equally applicable to exports of agricultural commodities from the United States to other countries.

The Steering Committee, (identified in the Purpose section to the report), asked the study team to respond to four questions. Although not organized around these questions, the study team’s conclusions relative to the four questions are:

1. What role do Systems Approaches play in guarding against the introduction of plant pathogens into the United States?

Systems Approaches are both scientifically and theoretically sound. The combination of quantifiable mitigation measures results in an increased level of phytosanitary security unattainable with any of the measures used alone. Qualitative assessments also result in Systems Approaches that are theoretically and scientifically sound when the assessments are appropriately conducted. Examples (Case Studies) of effective Systems Approaches are given which involve viruses, phytoplasmas, fungi, and bacteria, as well as combinations of pathogens. Examples also illustrate that Systems Approaches can be applied to seed, hardwood cuttings or plants, whole succulent plants, and plant products. The case studies also illustrate that Systems Approaches must be designed specifically for each country or region of a country, each pathogen or pathogens and for each pathogen/host combination.

Systems Approaches have been used successfully for more than 30 years for importation of plant products into the United States. They play an important role in allowing importations when single mitigation steps are not effective or practical. Systems Approaches also are important when there is uncertainty or unpredictability in the efficacy of a single mitigation practice. Addition of another independent practice gives further assurance of the reliability of the system.

2. What other approaches to guarding against introduction of plant pathogens are used and are they more valid or reliable?

For a mitigation strategy to rely on a single mitigation measure, that mitigation measure must be highly effective (approaching 100% effectiveness) in keeping unwanted pathogens from being brought in on plants or plant products. These measures may be effective in a given specific case but not in another. There are very few failures of official USDA -APHIS designed and implemented importation rules, whether single measure or Systems Approach. Many, if not most, quarantine pathogens that become established do so through a route unrelated to commercial importation. Indeed, to our knowledge, there are no examples of a failed Systems

Approach leading to the establishment of a quarantine pathogen in the U.S. Thus, it is best to state that carefully designed mitigation procedures which take advantage of biological weaknesses of pathogens are all sound. If they are scientifically and theoretically sound, provide an adequate degree of risk abatement, are properly implemented, and keep the pathogen at bay, it is difficult to determine “more valid or reliable” methods.

3. How is APHIS currently using Systems Approaches, why, and what can be done to make them better?

Most Systems Approaches to date were designed to prevent and mitigate risk of importation of a single pathogen on a single commodity. The mitigation plan for importation of Argentine citrus, established in 2000, was designed to prevent introduction of three pathogens into the U.S. via fresh citrus fruits. The region from which citrus could be imported from Argentina was a citrus canker disease-free area and with several other mitigation measures was perceived by U.S. growers to provide adequate protection against introduction of citrus canker into the U.S. However, sweet orange scab and citrus black spot both occur in the canker-free region. Numerous mitigation steps are incorporated into the plan, each of which reduces the likelihood of infective inoculum remaining on the fruit that is shipped. None of these measures is adequate to mitigate the pathogens by themselves, but together, in tests and commercial movement to date, the total plan has been effective. Some grower groups, however, were not satisfied that the plan was (is) adequate to prevent establishment of citrus black spot in U.S. production areas. A major concern was that the whole process of developing the plan was not transparent and they were not fully involved in developing the plan or in observing the trials conducted in Argentina.

The use of systems engineering processes is recommended to APHIS when developing the next Systems Approach. Systems engineering processes start with customer (grower, consumer, etc.) involvement and allow for continuous refinement of the Systems Approach as more experience is gained. Use of systems engineering is the major recommendation of this report to improve the system and the perception of the system.

4. How does APHIS’ use of Systems Approaches fit into the international safeguarding system?

This question is answered thoroughly in the Preface. The United States is a party to the World Trade Organization’s Agreement on the Application of Sanitary and Phytosanitary Measures and to the International Plant Protection Convention. The latter sets international standards for phytosanitary measures affecting trade. (IPPC, 1995). These standards require that phytosanitary measures be based on scientifically developed knowledge and understanding of the pathosystem.

Systems Approaches utilize sound scientific knowledge to allow movement of plants and plant products. Thus, they facilitate trade and allow countries to abide by the Sanitary and Phytosanitary Agreement.

Understanding the scope and effectiveness of available pest risk mitigation methods for a pathogen of quarantine concern is essential to the success of the Systems Approach. Many single treatment pest risk mitigation methods that provided an adequate level of quarantine security have been lost. Some otherwise effective pest risk mitigation methods have proven to be unacceptable due to negative impact on the commodity or the environment. Other methods may show diminishing efficacy over time. By combining those pest risk mitigation measures still available, an acceptable level of pest risk for imported host commodities can be achieved.

At times, the choice will prove straightforward. When no single control method used alone can achieve an acceptable level of quarantine pest risk without unacceptable damage to the commodity or prohibitive cost, the application of independent treatments with additive effects is essentially the only alternative to prohibition of import.

It's foreseeable, however, that in other scenarios a comparison and selection among alternative pest mitigation strategies would be necessary. If this evaluation considers a wide range of concerns (cost, feasibility, security, etc.), there may be instances when, on balance, a specific Systems Approach that is slightly less effective than a single-step mitigation strategy would be preferred. Each commodity/pathogen/country situation is unique. There is no "how to do it" manual.

In many cases, acquiring the information needed to enable development of an adequate Systems Approach for a particular commodity/pathogen combination will be quite challenging. At times, it will be impossible. In those cases where there is a considerable level of uncertainty about the efficacy of a specific Systems Approach, a degree of redundancy or "over-kill" may be required to ensure an acceptable level of quarantine pest security.

In addition, as with the application of any method, monitoring and verification are essential elements. Monitoring and verification must be maintained in order to detect changes in the pathosystem and to maintain stakeholder confidence. These essential elements also enable continuous improvement through the discovery and correction of error.

References

1. Burnett, W. 2001. APHIS' Use of Systems Approaches as They Relate to Plant Pathogens. Report submitted to study committee May 30, 2001.
2. Couey, H.M. and V. Chew. 1986. Confidence limits and sample size in quarantine research. *J. Econ. Entomol.* 79:887-890.
3. Finney, D.J. 1971. *Probit Analysis*, 3rd Ed. Cambridge University Press. IPPC. 1999.
4. IPPC. 2000. Integrated Measures for Pest Risk Management – Systems Approaches. Work Group Draft. 27 July 2000. Brisbane, Australia.
5. IPPC. 2000. Systems Approaches for Pest Risk Management. IPPC Secretariat Discussion Paper. January.
6. IPPC. 1995. International Standards for Phytosanitary Measures: Principles of Plant Quarantine as Related to International Trade. Plant Protective Service, Food and Agriculture Organization of the United Nations. pp. 9
7. Jang E.B. and H.R. Moffitt. 1994. Systems Approaches to achieving quarantine security. In *Quarantine Treatments for Pests of Food Plants*, Sharp, J.L. and G.J. Hallman (eds.) pp. 225-237, Westview Press, Boulder CO.
8. Kayhanian, M. and F. Martin. 1994. Systems Engineering Looks at AB39, The California Integrated Waste Management Act of 1989. *Proc. 4th Intl. Symp. Natl. Council on Systems Engineering*. Vol I:1039-1046.

9. Keizur, A.E. and B.W. Mar. 1994. Applying Systems Engineering and Icon-driven Simulation Techniques to the Waste Disposal Problem at Hanford, WA. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:873-879.
10. Lee, G.F., A. Jones-Lee, and F. Martin. 1994. Landfill NIMBY and Systems Engineering: A Paradigm for Urban Planning. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:991-998.
11. Liquido, N.J., R.L. Griffin, and K.W. Vick. 1997. Quarantine Security for Commodities: Current Approaches and Potential Strategies. Proc. Of Joint Workshops of the Agricultural Research Service and the Animal and Plant Health Inspection Service. June 5-9 and July 31-Aug 4, 1995. Beltsville, MD.
12. Mackey, Jr., W.F. and W.F. Mackey. 1994. A Systems Engineering Approach to Highway Design. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:633-642.
13. Mangan, R.L. and J.L. Sharp. 1994. Combination of multiple treatments. In Quarantine Treatments for Pests of Food Plants, Sharp, J.L. and G.J. Hallman (eds.) pp. 239-247, Westview Press, Boulder CO.
14. Miller, C.E., A.S. Green, V. Harabin, and R.D. Stewart. 1995. A Systems approach for Mexican Avocado – Risk Management Analysis. USDAAPHIS. 27 pp.
15. National Plant Board. NPB Plant Quarantine, Nursery Inspection and Certification Guidelines, found online at: <http://www.aphis.usda.gov/npb/figures/figure1.html>
16. Robertson, J.L. and H.K. Preisler. 1992. Pesticide bioassays with arthropods. Boca Raton, Florida: CRC Press.
17. Schneider, S.M., M.C. Shannon, D.L. Karlen, and C.R. Amerman. 1994. Application of Systems Engineering Methodology to the Design of an Agricultural Research Program. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:851-857.
18. Terry, W.S. 1994. Applied Systems Engineering: A View from the Trenches. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:881-887.
19. Walters, J.M. 1994. Systems Engineering Applied to Strategic Planning: The LASE Follow-on Study. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:889-895.
20. Wymore, A.W. 1994. Model-based Systems Engineering. System Engineering Journal 1:83-92.
21. Wymore, W., C. Onstad, and L. Lane. 1994. AGUAS: Design of an Agricultural Water Quality System. Proc. 4th Intl. Symp. Natl. Council on Systems Engineering. Vol I:837-844.



APPENDIX A – CASE STUDIES

The following six case studies were chosen to serve as examples of Systems Approaches of varying complexity. Some have been in use for more than 30 years and others have only recently been initiated. Some target an individual pathogen, others respond to the threat of introduction or establishment of multiple pathogens. Though the pathogen or pathogens may affect commodities in multiple locations, each Systems Approach described is uniquely fitted to the region from which the commodity is imported. Note, particularly, that though there are mitigation procedures in common between the Systems Approach implemented for Citrus Fruit from Argentina and the Systems Approach for Unshu Oranges from Japan and Korea, the two approaches are distinct. The Systems Approach for Argentina aims to exclude *not only* the bacterial pathogen that causes Citrus Canker, but also the fungal pathogens that cause Citrus Black Spot and Citrus Scab.

True potato seed from Chile's 'X' region: Managing multiple viral pathogens

European stone fruit yellows phytoplasma: Certified nurseries in six nations – Belgium, Canada, France, Germany, Great Britain, and The Netherlands

Brown rot of stone fruit caused by the fungal pathogen *Monilinia fructigena* honey: Government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands

Stone fruit and plum pox virus: Government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands

White rust of chrysanthemums caused by the fungal pathogen *Puccinia horiana*: Europe, East Asia, and specific South American countries

Citrus from Japan and Korea (Unshu Oranges) and Argentina

- a) Citrus canker caused by the bacterial pathogen *Xanthomonas campestris* pv. *citri*
- b) Citrus black spot caused by *Guignardia citricarpa*
- c) Citrus scab caused by multiple fungal pathogens
- d) Integration of measures for three diseases: Citrus canker, citrus black spot, and citrus scab

True potato seed from Chile's 'X' region: Managing multiple viral pathogens

Potato black ringspot virus (PBRSV) (also known as *Tobacco ringspot virus* Andean calico strain) is one of at least five viruses identified as infecting *Solanum tuberosum*, wild *Solanum* spp. and weed hosts found in the Andean highlands of South America. While authorities disagree whether this virus transmits via true potato seed, the perceived threat of introducing this or similar viruses to the United States via breeding stock warranted a long-standing embargo against the import of this commodity to the United States from any nation except Canada. In fact, the prohibition on import of potato seed was only relaxed in 1995 and then, only for breeding stock exported from a narrowly defined region in Chile.

This case study describes the implementation of a Systems Approach to reduce the risk of introducing PBRSV. The same approach has also been employed to prevent introduction of *Andean potato latent tymovirus* (APLV), *Arracacha B nepovirus* oca strain (AVB-O), *Potato yellowing alfamovirus* (PYV), and *Potato T trichovirus* (PVT). No single component of the Systems Approach described here is uniquely designed to prevent importation of PBRSV. Rather, when combined, these components aim to prevent transmission of any one of the five viruses listed above. For this study, then, PBRSV exemplifies the other four target viruses listed above. Yet, each of these viruses is a unique pathogen exhibiting a variety of symptoms, disease cycles and economic significance.

Distribution

The only confirmed reports of PBRSV are in Peru and Chile (along the mountainous border between the nations), but authorities suspect the virus may be present, though unidentified, in other Andean countries. The distribution of the other five viruses is similar. There are confirmed cases of each virus in Peru, and confirmed cases of APLV reported in Bolivia, Columbia, Uruguay, Paraguay and Argentina. Figure 4 shows the known distribution of each of the five viruses listed above.

Symptoms

Under Andean highland conditions, several cultivars of *Solanum tuberosum* develop calico-like symptoms when infected by PBRSV. Bright yellow areas on the margins and upper leaves gradually increase in size to form large patches. Most of the plant foliage may eventually turn yellow without stunting or leaf deformations. Plants that become infected during the current growing season show local and systemic necrotic spots and ringspots. Sometimes systemic necrosis also is observed.

Symptoms of PBRSV are persistent and under certain conditions and in some cultivars, the virus causes serious damage to the crop.

Disease Cycle

PBRSV transmission is suspected to be via one or more vectors, though none has been conclusively identified. As noted above, there is ample reason to be concerned that it is transmitted through true potato seed. The virus spreads locally by contact between plants and possibly through insect or nematode vectors.

International Dissemination

This virus is most likely to spread across geo-political boundaries as a result of trade in seed potatoes used by professional breeders. Because of the probability that any material of wild tuber-forming *Solanum* spp. originates ultimately from South America, the import of either tubers or true potato seed into the United States is strictly limited almost without regard to the country of export.

Control

As with all potato viruses, control of PBRSV depends on the production of high-quality seed potatoes from virus-free nuclear stock.

Systems Approach

Preventing the transport of the PBRSV and the other viruses described above hinges on establishing a method for producing virus-free potato seed. Since it is unclear what vectors might transfer PBRSV from neighboring hosts to plants being cultivated for export of germplasm, this pathogen serves as an excellent example of how a Systems Approach can be implemented.

The mitigation steps followed in Chile's 'X' region are as follows (Fig. 5).

Parent-Plant Propagation System

- Parental lines destined for Chilean production sites are developed in California, through a breeding program. Tubers from parent plants are disinfected and then stored until dormancy break. Tubers are then moved to a dark area until sprouting and disinfected again.
- This material is transferred to a quarantine area where meristematic tissue is taken from the sprout and cultured under aseptic conditions. The source of each tissue culture is accurately recorded, and the tissue is subcultured twice to provide sufficient material for virus testing. After tissue culturing, three individual plantlets are subjected to serological testing for 16 different viruses, including the five target viruses: PBRSV, APLV, AVB-O, PVY and PVT.
- Rapid multiplication of the virus-free plantlets occurs through micropropagation, and 1% of these plantlets are again tested for virus before shipment to Chile.

Micropropagation (at Chilean location)

- Micropropagation taking place in Chile is performed using aseptic methodology.
- Again a 1% sample of the micropropagated plantlets is tested for all 16 viruses.

Greenhouses

- Plantlets are transplanted in greenhouses located in isolated areas known to be free from traditional potato diseases.
- Greenhouse substrate is sterilized with steam.
- Aseptic procedures are followed in greenhouses.
- Greenhouses are equipped with window and door screens designed to prevent the entrance of aphids and other potential vectors.

Virus Testing

- Minitubers obtained from the greenhouse are virus tested.

Fields

- The fields where the male and female plants grow are located in a unique region of Chile (Region 'X'), which is naturally isolated from neighboring potato-growing regions. Chile is bounded by the Pacific Ocean to the west, a desert to the north, ice fields to the south, and the Andes Mountains to the east. Region 'X' is further isolated from potato viruses by the Chilean Ministry of Agriculture's strict controls over agricultural products entering Chile or being transported within the country.
- When fields are first used to grow potato plants for the purpose of breeding true potato seed, production sites must have been free from potato crops for ten years prior to planting. Once virus-free stock is initiated, a non-host crop will be grown in the field every two years. If a non-certified potato crop is grown in the field, another ten-year waiting period would ensue.
- Production sites are located at least 200 meters from any other potato crop.
- Fields and their perimeters are regularly scouted for weeds, and any weeds found are eliminated. Pesticide applications to control insect vectors occur throughout the season.
- Plants are tested for the target viruses (PBRSV, APLV, AVB-O, PVY and PVV) during growth at a sampling rate designed to provide 99% confidence of detecting an infection of 1% of plants. If a virus is discovered, all plants within one meter of the infected plant or plants are destroyed and remaining plants are re-tested for the target viruses.

Shipment

- Plantlets arriving in the United States are re-tested using nitrocellulose membrane-enzyme linked immunosorbent assay (NCM-ELISA) and nucleic acid spot hybridization (NASH) non-reagent tests to confirm the previous testing.

In this Systems Approach, the efficacy of risk mitigation is verified by viral testing. Efficacy is ensured by the eradication of infected plants at each stage of the production scheme. Procedures for production and maintenance of virus-free plant materials, and virus testing are two independent aspects in this Systems Approach.

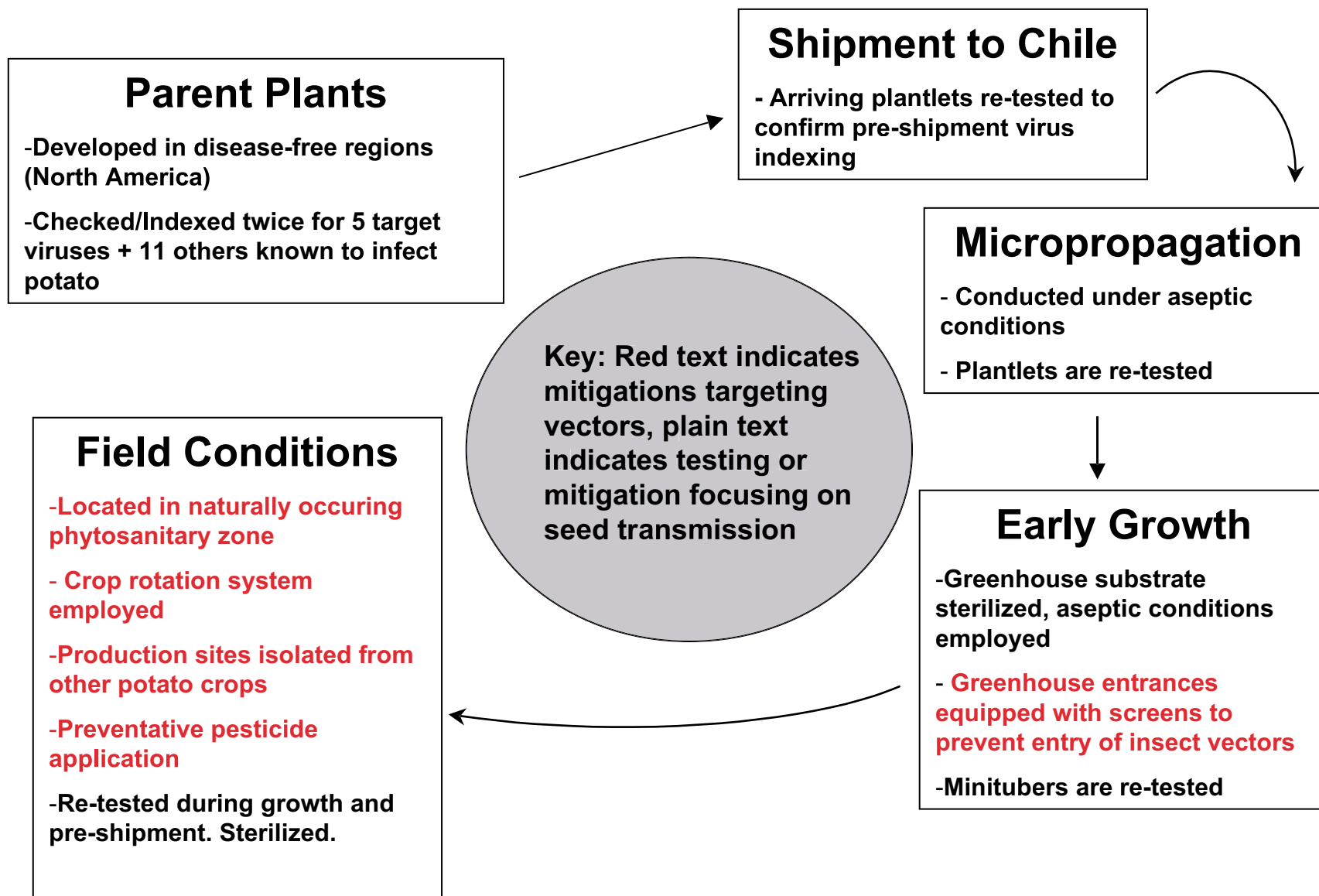
References

1. Salazar, L.F. January 1997. "*Potato black ringspot nepovirus*" In: Plant Viruses Online: Descriptions and Lists from the VIDE Database. Version: 16th (Brunt, A.A., *et al*, eds.), , published online at: <http://bioogy.anu.edu.au/Groups/MES/vide>
2. 7 CFR 319.37-2.
3. 7 CFR 319.37-5(o).
4. Smith, I.M., *et al*, (eds.) 1997. Data Sheets on quarantine pests for the European Union and for the European and Mediterranean Plant Protection Organization *in*: Quarantine Pests for Europe, Second Edition pp. 1177-1179, 1294-1297, 1302-1304, 1311-1313, 1321-1322.
5. Ministry of Agriculture, Chile. 1995. Production of Botanical Potato Seed for Export to the USA, Protocol VII. (Draft document, unpublished).

Figure 4. Andean potato virus distribution



Figure 5. Mitigation steps against potato viruses in production of potato breeding stock in Chile for use in the United States



European stone fruit yellows phytoplasma: Certified nurseries in six nations – Belgium, Canada, France, Germany, Great Britain, and The Netherlands

European stone fruit yellows is the relatively new name for the phytoplasma in Group X that causes decline of almonds, apricots, peaches and plums in Europe. Previously, this pathogen has been referred to as apricot chlorotic leaf roll, plum leptonecrosis, or European peach yellows. This phytoplasma is the predominant cause of decline and death of productive apricot, peach, and plum trees in Europe.

Distribution

Diseased apricots were first observed in France early in the 20th century. After the discovery of phytoplasmas in 1968, these pathogens were associated with declining stone fruit trees in all Mediterranean countries of Europe and as far north as Germany and recently England. With the development of molecular methods for grouping phytoplasmas and analyzing their nucleic acids, phytoplasmas infecting various stone fruits in these countries were found to be similar. Outside Europe, this pathogen has only been reported in Turkey.

Symptoms

In spring, diseased trees may be easily recognized when leaves emerge prematurely before flowers. Affected leaves are small, yellow, rolled, stiff and brittle. Trees infected when young show leaf symptoms throughout the tree, but old trees may initially have only a few twigs or a scaffold branch affected. Fruit may be small, bumpy, and drop prematurely. As fall approaches, leaves may abscise prematurely. Buds may break producing many weak shoots that are subsequently killed in winter.

Infected trees decline and eventually die within 1-4 years. Over this time, the tree exhibits poor growth, irregular and sparse flowering, few small fruits and discolored phloem. The speed of decline is influenced by the tree's age, environmental conditions, inherent susceptibility and rootstock type.

Some cultivars show few symptoms before dying the next winter. In general, apricots die more quickly if propagated on peach rootstocks rather than on plum rootstocks. Japanese plums decline more slowly than apricots.

Disease Cycle

This phytoplasma is spread in the field by one or more vectors that have not yet been identified. If this phytoplasma is similar to other stone fruit phytoplasmas, the vector or vectors will probably be phloem-feeding leafhoppers. Trees usually start showing symptoms 1-3 years after inoculation by vectors. Up to 20% of an orchard may be infected in a growing season. New infections occur near diseased trees or along borders of the orchard. In France, wild roses, ash trees, and hackberries in the vicinity of an apricot orchard were found to be infected. Up to 60% of the trees in an orchard have been killed within 10-15 years.

International Dissemination

The most important method of long distance dispersal of European stone fruit yellows phytoplasma is by the movement of diseased trees or budwood to uninfested areas. Since this phytoplasma, like all phytoplasmas, is too small to see, is confined to the phloem tissue, and causes no consistent symptom in dormant wood, the grower or nurseryman is unaware of its presence in transported nursery stock. After planting or propagation, the infected trees serve as a pathogen source for any local vectors that might be present.

This pathogen may be disseminated by the movement of infected wild roses, ash trees, hackberries and perhaps other native host plants. The risk associated with this pathway is difficult to assess due to the lack of essential biological data.

Seed transmission of phytoplasmas is not thought to be possible. Therefore, host plant seeds are not considered to be a risk for dissemination of this pathogen.

Control

In order to exclude European stone fruit yellows phytoplasma, Prunus hosts from affected countries must be tested in quarantine by grafting tissue collected from candidate plants onto sensitive indicator plants, or by using nucleic acid probes or polymerase chain reaction (PCR). Since this pathogen is unevenly distributed in infected budwood or trees, testing must be thorough, as well as accurate. Prunus species produced by approved foreign certification programs can also be imported with reasonable safety.

In Europe, growers must live with this pathogen. Their certification programs can produce trees free of this phytoplasma, but once planted these certified trees are vulnerable to infection by the feeding of vectors carrying the pathogen. Vector populations can be reduced by controlling weeds and leafhoppers in and around the orchard. Tolerant varieties may produce a good crop in severely affected areas. Injection of oxytetracyclines has been successful in suppressing phytoplasma multiplication in infected trees, but treating a whole orchard is not practical.

Systems Approach

Inspections to detect European stone fruit yellows phytoplasma will not be consistently effective at excluding this pathogen. These single-celled organisms are too small to see, they're buried in the phloem of affected plants, and symptoms in dormant wood are not readily diagnosed using most common methods employed at ports-of-entry inspections. Inspections during growth may detect leaf symptoms when the strain, host, and environment are optimal for symptom expression, but many suboptimal situations make pathogen introduction inevitable if inspection alone is used to identify and exclude infected plants or budwood.

The only effective methods of exclusion involve testing imported trees or budwood for phytoplasmas. This testing can be used to establish pest free areas or pest free production sites. At the present time, the United States does not recognize any pest free areas in Europe. In the case of pest free production sites, the United States accepts hosts from government research stations in five countries where trees have been tested and maintained free of this phytoplasma and other pathogens. This restriction reduces the risk of field spread from nearby infected plants that is inherent in importing the same hosts from certified nurseries located in infested countries.

Seeds of hosts are the only plant part that can be safely imported without pathogen testing. While the importation of host plant seed is considered to be safe, importation of seed from commercial cultivars is useless because commercial fruit tree cultivars don't breed true. However, the seed of host species used to produce rootstock seedlings could be safely imported.

Risk mitigation action initiated in 1980 include:

- Parent stock must be visually inspected, tested and found to be disease free.
- Plants must be inspected and certified as disease free prior to export.
- Plants must pass an inspection upon arrival to the United States.
- Plants must pass through two years of post-entry quarantine prior to being released.

Using the foregoing measures and performing appropriate audits of disease occurrence, the introduction of European stone fruit yellows phytoplasma (ESFYP) into the United States following accepted protocols has been and is likely to be prevented in the future. In this Systems Approach, inspection for disease and testing at all stages of production and post-entry quarantine for ESFYP of budwood sources and imported planting stock are independent steps for excluding this pathogen. Phytosanitary certification is dependent upon ESFYP monitoring and ESFYP testing.

References

1. Nemeth, M. 1986. Virus, Mycoplasma and Rickettsia Diseases of Fruit Trees. Martinus Nijhoff, Dordrecht, The Netherlands. 841 pp.
2. Seemuller, E. and J.A. Forster. 1995. European Stone Fruit Yellows. In: Compendium of Stone Fruit Diseases. (Ogawa, J.M., *et al*, eds.) APS Press, St. Paul, MN. pp. 59-60
3. 7 CFR 317.2.
4. 7 CFR 317.5(b)(2).



Brown rot of stone fruit caused by the fungal pathogen *Monilinia fructigena*: Government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands

Three species of *Monilinia* cause brown rot of stone fruits. *Monilinia fructicola* and *M. laxa* occur in the United States, but *M. fructigena* does not. *M. fructigena* was reported in Maryland once but was eradicated. In addition to stone fruits, *M. fructigena* also causes damage on pome fruits and other Rosaceous plants.

Distribution

M. fructigena occurs throughout Europe and Asia, as well as in parts of Africa and South America. Its discovery in the United States resulted in a program leading to its eradication (Fig. 6).

Symptoms

Under favorable conditions, blossom blight may occur in spring. The fungus spreads into twigs and eventually branches, causing twig blight and branch cankers. Gumming may occur at the margins of infected areas. Cankers that girdle branches cause the collapse of distal portions of the branch. Fruit develop firm brown circular spots, especially around injuries, which spread rapidly to envelop the entire fruit. Conidia emerge on the surface of the brown rot. Ripe fruit may develop brown rot lesions during storage.

Disease Cycle

This fungus overwinters in dead tissue, such as fruit mummies, twigs and branch cankers (Fig. 7). In early spring, sporodochia with conidia (asexual stage) develop on fruit mummies, blighted blossoms, or infected twigs and branches. In rare cases, apothecia (sexual stage) may develop from fruit mummies or debris on the orchard floor. Spores are disseminated by wind and rain. Warm temperatures and wet conditions favor spore germination and infections. Insects may facilitate infection by causing injuries or by transporting spores to susceptible tissue. Conidia from blossoms, twigs and branch cankers are the inoculum for fruit infections. Fruit can be infected by direct penetration of the cuticle, stomata or trichomes and through cracks and injuries. Conidia are produced throughout the growing season and can infect fruit in any stage of its development. Decay in storage results from infections just before harvest. Infection of the twigs and branches to form cankers and fruit to form mummies assures fungus survival from season to season.

International Dissemination

The highest risk of long distance dispersal is movement of infected trees or budwood to uninfested areas. Even though large twig cankers may be evident, recent or dormant infections may not be detectable. Once planted or propagated, infected wood will inevitably be exposed to the warm wet conditions necessary for conidia production and the wind and rain necessary for conidia dispersal.

Rotting fruit or recently infected fruit also may carry this brown rot fungus into the United States. However, the usual methods of transportation and storage of fruit minimize the risk of establishment. Rosaceae susceptible to this fungus are quite prevalent throughout the United States, and environmental conditions are favorable for infection during the growing season.

Properly cleaned seed presents a low risk of transmission and spread.

Control

Protective fungicide treatments for both blossoms and fruit are the primary methods of control. These pesticide applications are spaced throughout the growing season to protect fruit up to harvest, minimize storage rot, reduce sporulation, and decrease overwintering inoculum. The removal of fruit mummies and infected twigs or branches and insecticide applications to control vectors and fruit wounding insects also can help to reduce *M. fructigena* damage.

Systems Approach

Inspections to detect *M. fructigena* in dormant budwood, trees or fruit may be successful in finding large cankers or lesions, but it is doubtful whether the smallest and most recent infections will be detected. Various treatments or storage conditions may reduce the risk. Safe disposal of rotten fruit or infected wood is a must. Host plant material imported for use as propagative materials should be held in a quarantine containment facility or field plot well isolated from other host plant materials in the family Rosaceae.

Steps initiated in 1980 to mitigate the risk of spread into the United States include:

- Parent stock must be visually inspected, tested and found to be disease free.
- Plants must be inspected and certified as being disease free prior to export.
- Plants must pass an inspection upon arrival to the United States.
- Plants must pass through a two-year post entry quarantine prior to being released.

Introduction of *M. fructigena* into the United States has been and is likely to be prevented in the future using the foregoing Systems Approach. In this Systems Approach, inspection for disease and testing of budwood sources and other propagative materials, fruit and imported planting stock for *M. fructigena* during production and post-entry quarantine are independent steps. In addition, fungicide treatments to protect fruit from infection, and storage conditions to reduce sporulation and reduce inoculum are also independent aspects of this Systems Approach. Phytosanitary certification is dependent on inspection for disease and pathogen testing.

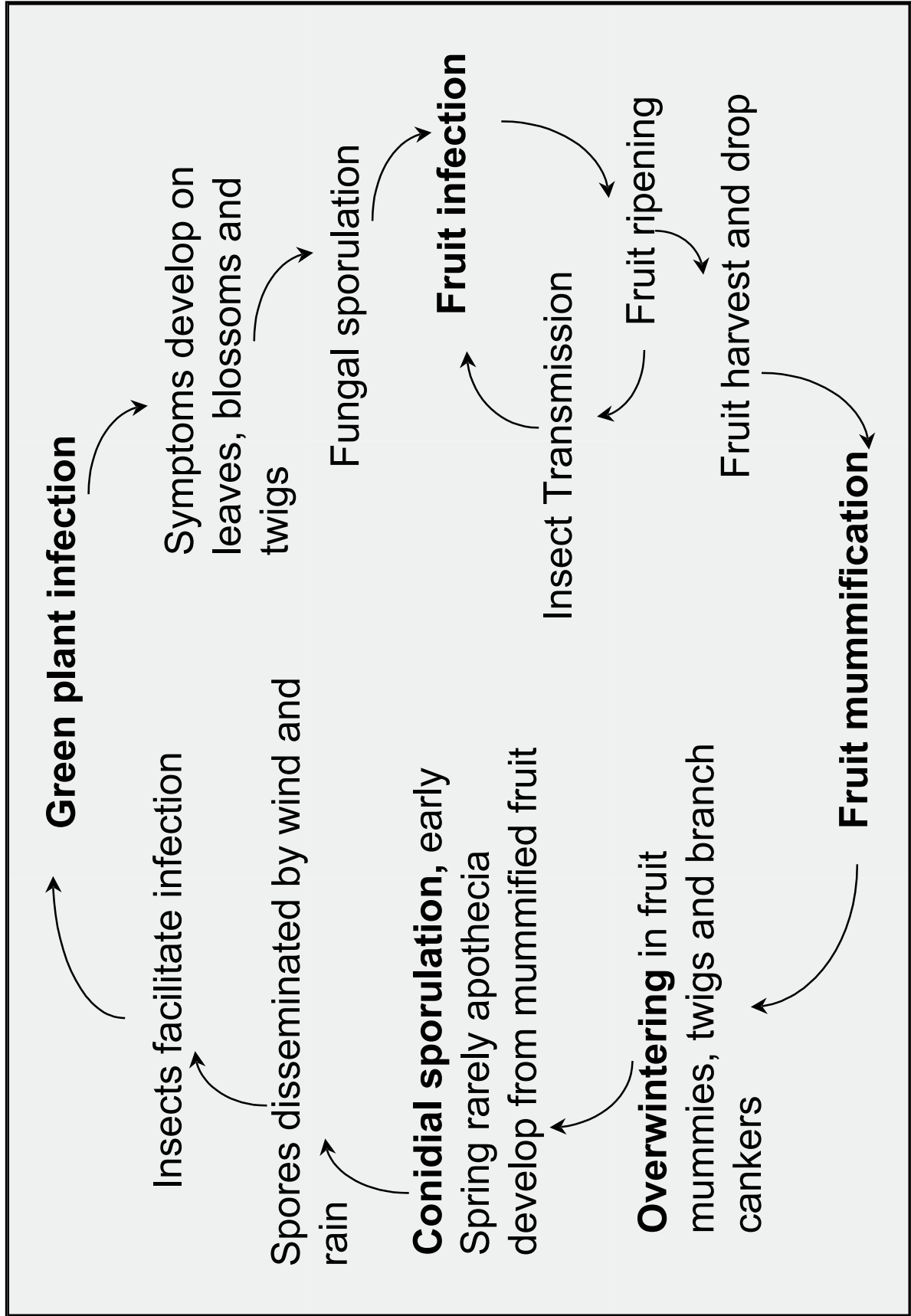
References

1. CAB INTERNATIONAL. 2000. Crop Protection Compendium. Wallingford, UK: CAB INTERNATIONAL.
2. Chang, L.W.H. 1986. A fruit brown rot. PNKTO No. 76. USDA APHIS, 14 pp.
3. Ogawa, J.M., E.I. Zehr and A.R. Biggs. 1995. Brown Rot In: Compendium of Stone Fruit Diseases. (Ogawa, J.M., *et al* eds.) APS Press, St. Paul, MN. pp. 7-10.

Figure 6. Brown rot (*Monilinia fructigena*) distribution



Figure 7. Disease cycle of brown rot caused by *Monilinia fructigena*.



Stone fruit and plum pox virus: government research stations in five nations – Belgium, France, Germany, Great Britain, and The Netherlands

Plum pox virus (PPV), also called Sharka, is the most damaging pathogen of stone fruits in Europe. Serious losses in European plum, Japanese plum, peach, nectarine and apricot are common in Central and Eastern Europe. Occasionally almond may be infected. Sour cherry and sweet cherry have been infected by unique PPV strains in Southeastern Europe. The most common strains, the D and M strains, are not known to infect cherries. Serious losses have only been documented for the D and M strains of this virus.

Information about the biology of PPV and procedures for its mitigation should the virus be introduced into the United States were developed in APHIS-PPQ's New Pest Response Guidelines for potyviridae (USDA, 1994). Much of the information contained in these guidelines is appropriate for development of a Systems Approach.

Distribution

PPV was first observed around 1918 in Bulgaria. During the next 50-60 years, the virus was spread throughout Europe except for certain areas of Scandinavia. More recently, the virus has been found in Turkey, Syria, Egypt, Chile, India, the United States (PA), and Canada (Ontario) (Fig. 8).

Plum pox is being eradicated in the United States. In Canada, the Canadian Food Inspection Agency has negotiated a three-year program with the industry and other stakeholders. On the Niagara peninsula, the effort is being characterized as “rapid containment.” Unlike in the United States, the only trees that are being removed are in groups of four – as represented by positive, four-tree samples.

Symptoms

Symptoms vary with the cultivar, virus strain and environment. In some situations, cultivars may exhibit leaf and fruit symptoms; other cultivars may have only leaf symptoms and others only fruit symptoms.

Symptoms may begin in young leaves as vein clearing and develop into chlorotic spots, rings or lines during spring and early summer. In some cultivars, chlorotic symptoms may turn necrotic. In others, chlorosis may be transient and fade in the summer heat. Twisting and leaf distortion may occur in peach leaves. Symptoms may be localized or scattered in the tree, due to uneven virus distribution.

Fruit symptoms appear as chlorotic rings or blotches in unripened fruit. Necrosis may develop in some varieties. In other cases, fruit may become deformed with bulges and irregular grooves and depressions. Red rings or spots may occur on the stones of affected fruit. Fruit may be fibrous and lack flavor. Fruit of some cultivars may drop prematurely causing total crop loss.

Disease Cycle

Plum pox is a potyvirus that is spread locally by many aphid species (Fig. 9). The virus does not persist in an aphid vector after it has been acquired from an infected source. An aphid vector may acquire the virus by merely probing infected tissue. Actual feeding or colonization of infected trees is not required. Known vectors are widely distributed throughout the United States wherever stone fruits are grown. Infection results when an aphid vector probes an infected leaf, acquires the virus, and then probes a healthy leaf within seconds or minutes after acquisition. Protective pesticides have not been effective at preventing infection because transmission occurs quickly upon probing of host plant tissue by a viruliferous aphid. However, under certain circumstances, insecticides can slow virus spread by reducing vector populations.

After transmission, virus spread within a healthy tree may be slow and erratic. Initially, a few areas on one or two limbs may be infected and only a few of these may show leaf symptoms. Aphids may acquire and further spread the virus from a tree before the tree begins to show symptoms or tests positive for infection. In fact, PPV may not become systemic and show obvious symptoms in a large tree until years after the initial inoculation.

Some studies suggest that optimal transmission occurs in May-June and in September-October, but so many aphid species are known to be vectors that transmission at some level may occur throughout the growing season.

Viruliferous aphids will transmit PPV to any nearby hosts, whether they are commercial cultivars, ornamentals or wild *Prunus* species. With strains in the D group from western Europe, the natural host range seems to be confined to *Prunus* species. However, reports from Eastern Europe suggest that walnut, ornamentals, and some weeds may become naturally infected with strains from these localities.

International Dissemination

Long distance dispersal of PPV is by the movement of diseased trees or budwood to uninfested areas. Since this virus is too small to be observed with the unaided eye or a conventional microscope and causes no consistent symptom in dormant propagating material, the commercial grower or nurseryman is unaware of the presence of PPV in his or her nursery stock. Once infected trees are planted or propagated in a new location, local aphids begin spreading PPV as soon as new infected leaves emerge.

Seed transmission, thought to be a second means of long distance spread by some, is controversial. Many studies in Western Europe with D strains and local cultivars failed to detect seed transmission of PPV, but some research in Eastern Europe showed seed transmission at low levels with their strains and cultivars.

Control

Many countries that are free of PPV try to prevent its entry. *Prunus* species imported from infested countries are held in secure post-entry quarantine facilities and tested using sensitive indicator plants, enzyme linked immunosorbent assay (ELISA) serology, or reverse transcriptase-polymerase chain reaction (RT-PCR). Foreign country fruit certification programs, with a demonstrated capacity for excluding the plum pox virus from stone fruit planting and propagative stock, are a possible source of clean stock for safe importation.

In some countries, PPV is confined to certain areas by containment and/or suppression programs. The French have been successful in confining PPV to southeastern France, and the Dutch attempt to eradicate the virus whenever they find it. Unfortunately, none of the European countries have been successful in eradicating PPV entirely from their country for sustained periods of time.

Countries where PPV is widespread are trying to live with it. Their stone fruit tree certification programs can produce PPV-free trees, but aphids carrying the virus from nearby infected trees eventually infect certified trees planted in infested areas. Plum, peach and apricot crops of reasonable quality are only possible using tolerant varieties. Transgenic virus-resistant stone fruits have shown promise under these conditions.

Systems Approach

Inspections to detect the presence of PPV will not be consistently effective at excluding this pathogen. The virus is too small and symptoms in dormant wood are too rare for inspections at ports of entry to be effective. Inspection during the growing season may detect foliar and fruit symptoms when the strain, host, and environment are optimal for symptom expression. Suboptimal combinations make PPV introduction inevitable where visual inspection and exclusion from shipment are used as the sole risk mitigation measure.

The only effective methods of exclusion involve the use of virus testing methods. Testing can be used to establish pest free areas or pest free production sites. For pest free areas, the foreign plant protection organization must demonstrate by acceptable surveys that PPV does not occur in the designated area and will not be introduced into that area because of an effective quarantine program. Monitoring surveys over time will also be needed. The surveys and quarantine programs must involve testing trees for PPV. For pest free production sites, the foreign plant protection service must have an acceptable certification program which involves testing mother plants for PPV and controlled propagation from these tested trees in a manner that minimizes the probability of PPV spread to these certified trees before export.

The United States currently accepts PPV hosts only from government research stations in five European countries where the trees have been tested and maintained free of PPV. Limiting importation to host materials originating from government research stations reduces the risk that is inherent in importing the same hosts from producing stock in an infested area or country. Plants imported from government research stations are inspected and must also go through a two-year post entry quarantine before their release. Cherries in the subgenus *Cerasus* can be imported in commercial quantities from nurseries in approved certification programs in these five countries.

The efficacy of this Systems Approach is dependent upon PPV detection by testing. Establishment and maintenance of plum pox-free areas via phytosanitary regulations based on disease surveys are independent aspects of this Systems Approach. The testing of budwood source trees and controlling conditions during propagation to minimize the chances of PPV spreading to certified trees also are independent aspects of the Systems Approach.

References

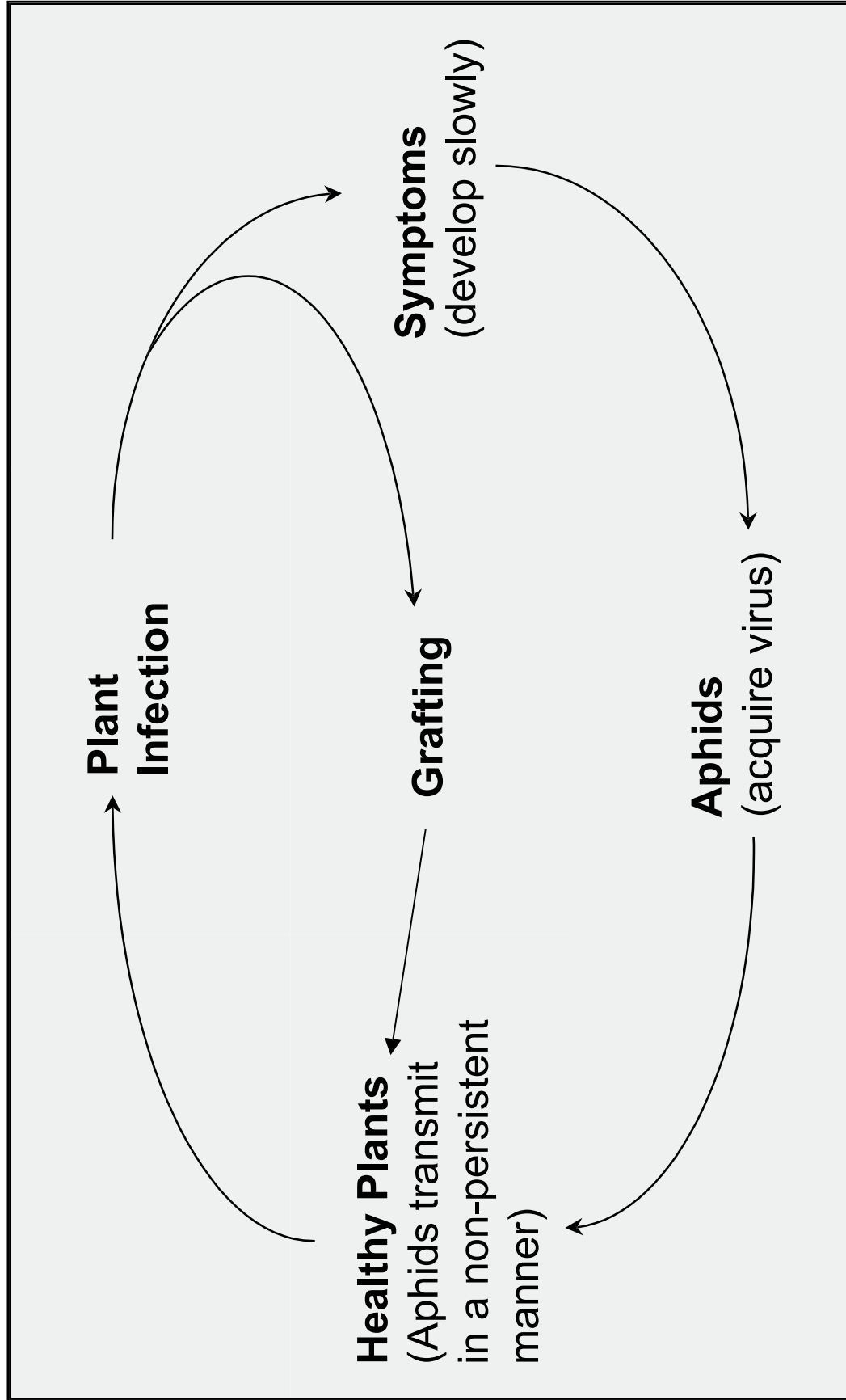
1. CAB INTERNATIONAL. 2000. Crop Protection Compendium. Wallingford, UK: CAB INTERNATIONAL.
2. Nemeth, M. 1986. Virus, Mycoplasma and Rickettsia Diseases of Fruit Trees. Martinus Nijhoff, Dordrecht, The Netherlands. 841 pp.
3. Adams, A.N. 1995. Plum Pox Virus. In: Compendium of Stone Fruit Diseases (Ogawa, J.M., *et al* eds.). APS Press, St. Paul, MN.
4. USDAAPHIS PPQ. 1994. New Pest Response Guidelines Potyviridae. (Stibick, J.N.L., ed.) pp. 1.1-5.7
5. 7CFR 319.37-2.
6. 7CFR 319.37-5(b)(2)



Figure 8. Plum pox distribution



Figure 9. Disease cycle of plum pox virus



White rust of chrysanthemums caused by the fungal pathogen *Puccinia horiana*: Europe, East Asia, and specific South American countries

White rust of chrysanthemums is caused by the fungus *Puccinia horiana*. Chrysanthemums are the only known host of *P. horiana*. The chrysanthemum genera most susceptible include *Dendranthema*, *Nipponanthemum*, *Leucanthemella* and *Ajania*. Leaves, stem and inflorescence can all be infected.

Distribution

White rust was first identified from Japan in 1895. Its subsequent distribution appears to have been to China and then South Africa. Infestations into Europe came from both Asia and Africa. Australia and New Zealand infections are of fairly recent origin with the infested areas of Southern Australia, Tasmania and Western Australia being under active control. *Puccinia horiana* was introduced repeatedly into the Western Hemisphere during the last three decades. Its current distribution includes every arable continent (Fig. 10).

North America has actively initiated eradication and exclusion programs to prevent further introductions and spread of the pathogen. In the United States, a control program focused on preventing the disease in commercial production operations has been implemented.

Symptoms

Following infection with *P. horiana*, the upper surfaces of chrysanthemum leaves exhibit small pale green-yellow-tan spots up to 5 mm in diameter. The corresponding areas on the lower leaves are initially pinkish-white. As the spots enlarge, raised pinkish pustules are seen which change to white with the production of basidiospores as they mature. With severe infections, sori sometimes develop on bracts and stems. Florets occasionally exhibit necrotic flecking with pustules.

Disease Cycle

Puccinia horiana is an autoecious rust. Following conditions of high humidity coupled with a film of moisture, with a temperature range of 4-23°C with an optimum of 17°C, bicellular teliospores germinate to produce unicellular basidiospores, which are dispersed into the air. Air currents distribute the spores to chrysanthemums to initiate new infections. For infection to occur, conditions of high humidity with a film of moisture for a minimum of 5 hours are needed. While the temperature range for infection by basidiospores to occur is 17-24°C, no optimum temperature has been noted. Basidiospores are very sensitive to desiccation at a relative humidity less than 90%. The incubation period from infection to initial symptoms is usually 7-10 days but short periods of high temperatures can prolong this period for up to 8 weeks. Teliospore production begins a few days following the development of symptoms (Fig. 11).

International Dissemination

Even though basidiospore dispersal is known to occur over distances of 700 m, long range spread of the spores would not be likely because of the spores' sensitivity to desiccation. White rust is more commonly spread on infected cuttings and plants from greenhouse grown chrysanthemums and cut flowers, as they are distributed around the world.

Control

Preventive spraying with fungicides controls the disease but is not cost effective. Biological control using *Verticillium lecanii* has shown some promise in greenhouses. Breeding for resistance is ongoing with numerous resistant varieties available. However, a variety resistant to one strain of the fungus may be susceptible to a different strain. Exclusion and eradication strategies are commonly employed to control the disease.

Systems Approach

A Systems Approach to circumvent further introduction of *P. horiana* into the United States was initiated in 1980. The specific risk mitigation measures include:

- Parent stock must be visually inspected, tested and found to be disease free.
- Plants must be inspected and tested once a month for 4 months prior to export.
- Plants must pass an inspection upon arrival in the United States.
- Plants must pass through 6 months of post entry quarantine after entry into the United States. (Inspections confirming the material's disease-free state continue for 8 times the normal disease cycle time from infection through sporulation before importation of plants into the United States and continue through 12 times the normal disease cycle time from infection through sporulation during the post-entry quarantine period.)

The introduction of white rust into the United States using the foregoing Systems Approach is not likely. In this Systems Approach, inspection of parent stock for disease, testing for *P. horiana*, application of protective fungicides, post-entry quarantine, and eradication of diseased plants are independent steps. Phytosanitary certification is dependent on inspection for disease and pathogen testing.

References

1. CAB INTERNATIONAL. 2000. Crop Protection Compendium. Wallingford, UK: CAB INTERNATIONAL.
2. Horst, R.K. and P.E. Nelson. 1997. White Rust. In: Compendium of Chrysanthemum Diseases. (Horst, R.K. and Nelson, P.E., eds.) APS Press, St. Paul, MN. pp. 19-20.
3. 7 CFR 319.37-2.
4. 7 CFR 319.37-5(c).

Figure 10. Chrysanthemum white rust distribution

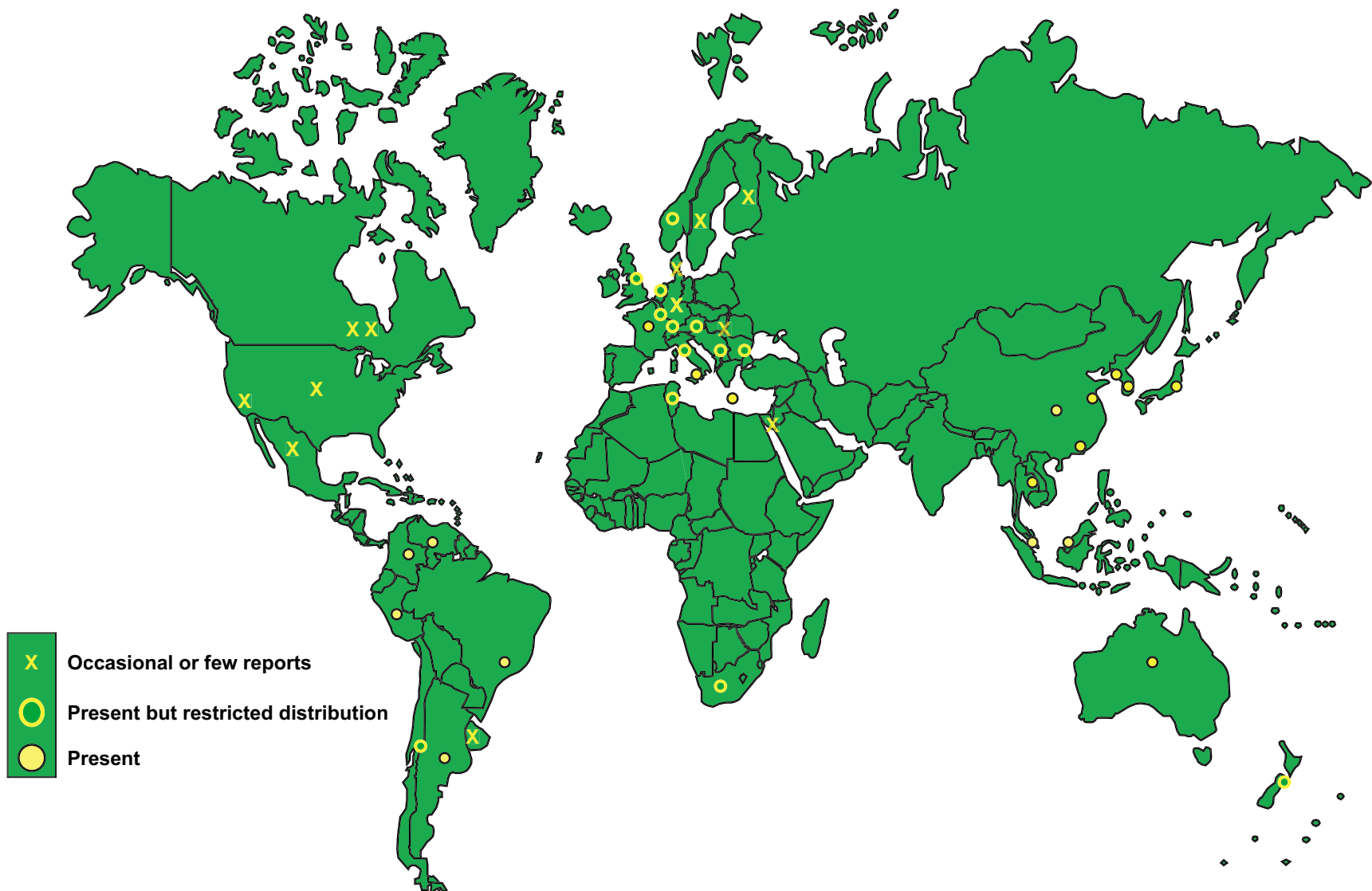
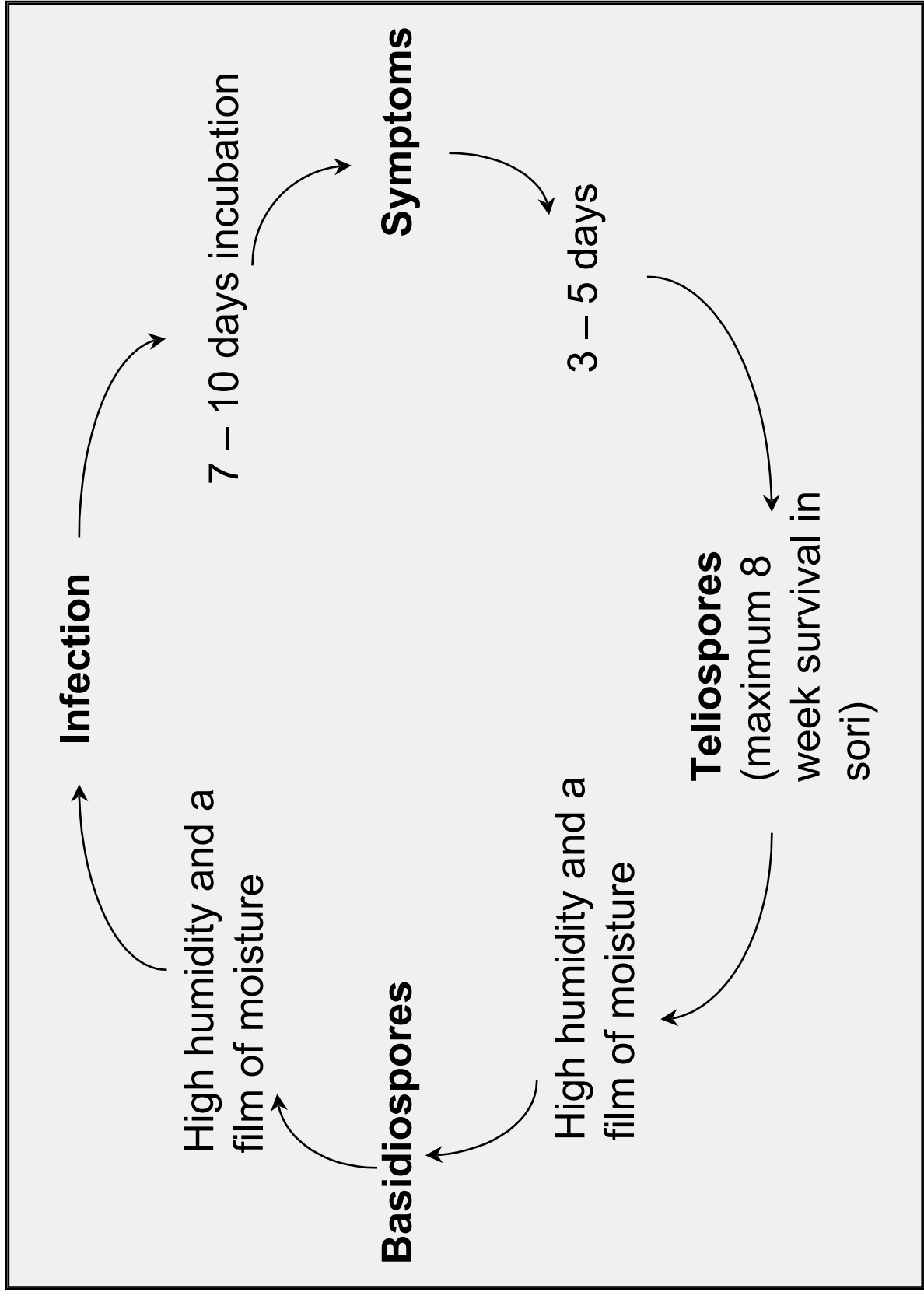


Figure 11. Disease cycle of chrysanthemum white rust caused by *Puccinia horiana*.



Citrus from Japan and Korea (Unshu Oranges) and Argentina

a) Citrus canker caused by the bacterial pathogen *Xanthomonas campestris* pv. *citri*

Citrus canker is caused by a bacterium, *Xanthomonas campestris* pv. *citri* = *X. axonopodis* pv. *citri*. Strains of the bacterium vary in virulence and aggressiveness with respect to host, cultural and physiological characteristics, bacteriophage sensitivity, serology, DNA-DNA homology, and genomic fingerprinting (e.g., restriction fragment length polymorphism (RFLP) and amplified fragment length polymorphism (AFLP) analyses). This pathogen is believed to have originated in Asia where the most aggressive (Group A) strains occur.

Group A (Asiatic canker), group B (cancrosis B), group C (Mexican lime canker), and group D (citrus bacteriosis) are distinguished on the basis of host specificity and pathogen aggressiveness. The restricted host ranges and weak pathogenicity of group B, group C and group D strains is widely recognized.

Citrus canker affects the economy of countries that have the disease as well as those countries that do not. It results in:

- Reduced marketability due to blemished fruit.
- Reduced fruit yield (e.g., premature fruit drop) of susceptible species/varieties.
- Reduced tree vigor (e.g., terminal dieback, defoliation) of susceptible species/varieties.

Increased costs to consumers/taxpayers results from implementation of additional disease-specific phytosanitary measures (e.g., eradication program, regulation of movement of fruit and/or plant propagating material, additional protective bactericidal/bacteriostatic sprays).

Loss or restriction of market development/maintenance/enhancement occurs from areas where the pathogen is introduced and becomes established, and/or where the disease is endemic.

Distribution

The distribution of *X. campestris* pv. *citri* is shown in Figure 12. A complete listing of occurrences can be found in CAB International 2000.

The geographical distribution of *X. campestris* pv. *citri* differs for different types of citrus canker. Canker A (Asiatic canker) is found in Asia, South America, Oceania and the United States. This strain is the predominant and potentially the only strain still found in nature. While canker B (Cancrosis B) has been reported in South America, canker C from Brazil and canker D from Mexico, neither they nor the diseases they cause are found in the field anymore.

X. campestris pv. *citri* has been eradicated from Australia including Thursday Island and South Africa.

Symptoms

Fruit lesions vary in size because the rind is susceptible for a longer time than the leaves and are subject to multiple infection cycles. Fruit and stem lesions are up to 1 mm deep and superficially resemble those formed on the leaves.

Following infection, symptom development depends upon host, plant part and age of tissue, and environmental conditions at the time of infection. On leaves, lesions start as small circular spots 2-10 mm in diameter. As the leaf lesions age, they may become irregular. Since leaves are only susceptible for a short period of time, infection is usually restricted to a single occurrence. Therefore, lesions tend to be about the same size and tend to aggregate at the leaf margins, leaf tip, or on a restricted area on the leaf. Infections can be increased by injury resulting from wind-caused abrasion and feeding of the Asian leaf miner (*Phyllocnistis citrella*) to the point that field resistance and tolerance are negated.

Lesions develop as light yellow, raised, spongy eruptions on the surface of leaves, twigs and fruits. As the lesions enlarge, the spongy eruptions begin to collapse and brown depressions appear in their central portion, forming a crater-like appearance. The edges of the lesions remain raised above the surface of host tissue and are characterized by having a greasy appearance. As the disease advances, the central portions become grayish-white, hard and appear as corky dead tissue with a rough surface surrounded by yellow halos. Canker lesions retain the erupted and spongy appearance under dry conditions, whereas they quickly enlarge and turn to flat lesions with a water-soaked appearance with frequent rain. The lesions of canker groups B, C and D are generally similar in appearance and histology to those of canker A, but they are significantly smaller.

The darker developing lesions on lemons and limes, together with the water-soaked margin that develops around the necrotic tissue, which is easily viewed with transmitted light, are useful diagnostic symptoms for canker.

Disease Cycle

X. campestris pv. *citri* survives in lesions in leaves, stems and fruits (Fig. 13). It can also survive on woody branches for several years. During periods of free moisture on the lesions, the bacteria ooze out and can be dispersed to infect receptive host tissue. Wind-driven rain is the primary mode of dispersal. Winds in excess of 8 m/sec contribute to successful penetration of the bacteria through the stomatal pores or wounds made by insects, blowing sand, or thorns. Injury resulting from pruning followed by environmental conditions favorable to the dispersal of the causal bacteria can result in severe infections.

X. campestris pv. *citri* continues to multiply while the lesion is expanding. The number of bacteria produced is dependent upon the susceptibility of the host and tissue infected. The bacteria remain viable in the margins of leaf lesions and fruit until they fall. Exposed bacteria that have oozed onto the leaf surface begin to die when conditions are dry. Exposure to direct sunlight accelerates bacterial death. Survival of exposed bacteria is only a few days if in the soil and only a few months in infected plant debris that is decomposing in the soil. However, the bacteria can remain viable for years in infected plant debris that is dry and free of soil.

Epidemiology

Host resistance to infection increases as the plant tissues age. Nearly all infections occur on the leaves and stems during the first 6 weeks of growth within a season. The fruit rind is most vulnerable during the first 90 days after petal fall. Fruit and foliage resistance is directly related to cuticle formation. As the cuticle thickens, resistance increases.

Environmental conditions delaying tissue maturation or promoting new shoot emergence favor disease

development. Most spread of the bacteria is over short distances, i.e., within a tree canopy or to neighboring trees. While some severe meteorological events can contribute somewhat to relatively short distance spread of the pathogen with concomitant increase in disease incidence, long distance dispersal of the pathogen is largely through the movement of diseased propagating material such as budwood, rootstock seedlings or budded trees. There is no record of seed transmission of *X. campestris* pv. *citri*. Dispersal can occur from workers carrying the bacteria on their person and equipment unless properly disinfested. Long distance spread of the pathogen can also occur if infected cull fruit are deposited near citrus orchards. Infected commercial fruit also can result in long distance spread when it is transported to uninfested areas and subsequent handling results in the transfer of bacteria to citrus trees. Boxes carrying infected fruit also have been implicated in long distance dispersal.

Control

Exclusion is the first line of defense against citrus canker. Much of the credit for the fact that citrus canker does not occur in all citrus production areas where environmental conditions are conducive to development of the disease is due to restrictions on the importation of propagating materials and fruit from infected areas. If new canker infestations in a previously uninfested area are detected before they are well established and widespread, removal and destruction of the infected trees and their uninfested, but exposed, neighbors is an accepted form of eradication.

In the early 1900's, canker was reported in South Africa, Australia and the United States (Gulf States only) but was eliminated through the implementation of orchard inspections, quarantines, and on-site removal and destruction of infected trees. Eradication programs are ongoing in Florida where new infections are found.

Integrated disease management is employed in areas where canker is a major problem. Integrated management includes the use of windbreaks, leafminer control, applications of copper sprays, and the use of resistant varieties.

Systems Approach

Development and implementation of a Systems Approach has effectively prevented the introduction of the citrus canker pathogen into the United States from Japan and Korea. Integrated pest management actions lend themselves to the Systems Approach concept. The establishment of disease-free groves or production areas, followed by the application of additional risk mitigation measures, reduces the risk of artificial spread from these infested countries to a miniscule level.

In the case of United States importation of Unshu oranges from citrus export regions in Japan and Korea, host susceptibility is an important, fundamental consideration. Unshu orange (*Citrus unshui*) resistance to *Xanthomonas campestris* pv. *citri* infection is moderate to high. It is the only species permitted to be grown for production in citrus export regions. These practices are incorporated as part of the following Systems Approach, which help prevent the artificial spread of the pathogen to the United States (Fig. 14):

- Unshu oranges must be grown in a Citrus Canker-free production area.
- A 400-meter buffer zone must be maintained around the canker-free area.
- Only Citrus Canker-resistant species can be grown in the buffer zone.

- Visual inspections for Citrus Canker are conducted in the groves at packing to verify freedom from disease.
- All fruit must be surface sterilized before packing.
- All tissue paper wrappings and shipping boxes must be labeled with the distribution requirements.
- The fruit must be inspected to ensure that all requirements have been met prior to its shipment to the United States.
- The fruit may be distributed only to non-citrus producing states or territories.

This System Approach is based on several independent measures that include establishment and maintenance of canker-free production areas, disease surveys, host resistance and chemical sprays (e.g., copper-containing compounds) to minimize disease incidence; cultural practices to reduce pathogen spread (e.g., windbreaks,) and reduce inoculum (e.g., by pruning or defoliation); disease forecasting for effective timing of chemical spray applications; post-harvest disinfestations of fruit; and restricted distribution of fruit in the importing country. Some measures have dual purposes. For example, measures that reduce disease incidence (e.g., disease-free production areas, host resistance, and chemical sprays) also reduce inoculum levels, reducing the chances for fruit to become infected or contaminated. Certification is based on adequate implementation of these measures.

References

1. CAB INTERNATIONAL. 2000. Crop Protection Compendium. Wallingford, UK: CAB INTERNATIONAL.
2. Civerolo, E.L. 1985. Comparative characteristics of *Xanthomonas campestris* pv. *citri* variants. In: Abstracts on the genus *Xanthomonas*. Fallen Leaf Lake Conference, Fallen Leaf Lake, South Lake Tahoe, California, September 20-23, 1985, 24 pp.
3. Schaad, N.W., A.K. Vidaver, G.H. Lacy, K. Rudolph, and J.B. Jones 2000. Evaluation of proposed amended names of several *Pseudomonas* and *Xanthomonas* and recommendations. *Phytopathology* 90:208-213.
4. Gottwald, T.R. and J.H. Graham. 2000. Canker. In: Compendium of Citrus Diseases. 2nd Edition (Timmer, L.W., Garnsey, S.M., and Graham, J.H., eds.) APS Press, St. Paul, MN. pp. 5-7
5. 7 CFR 319.28.



Figure 12. Citrus canker distribution

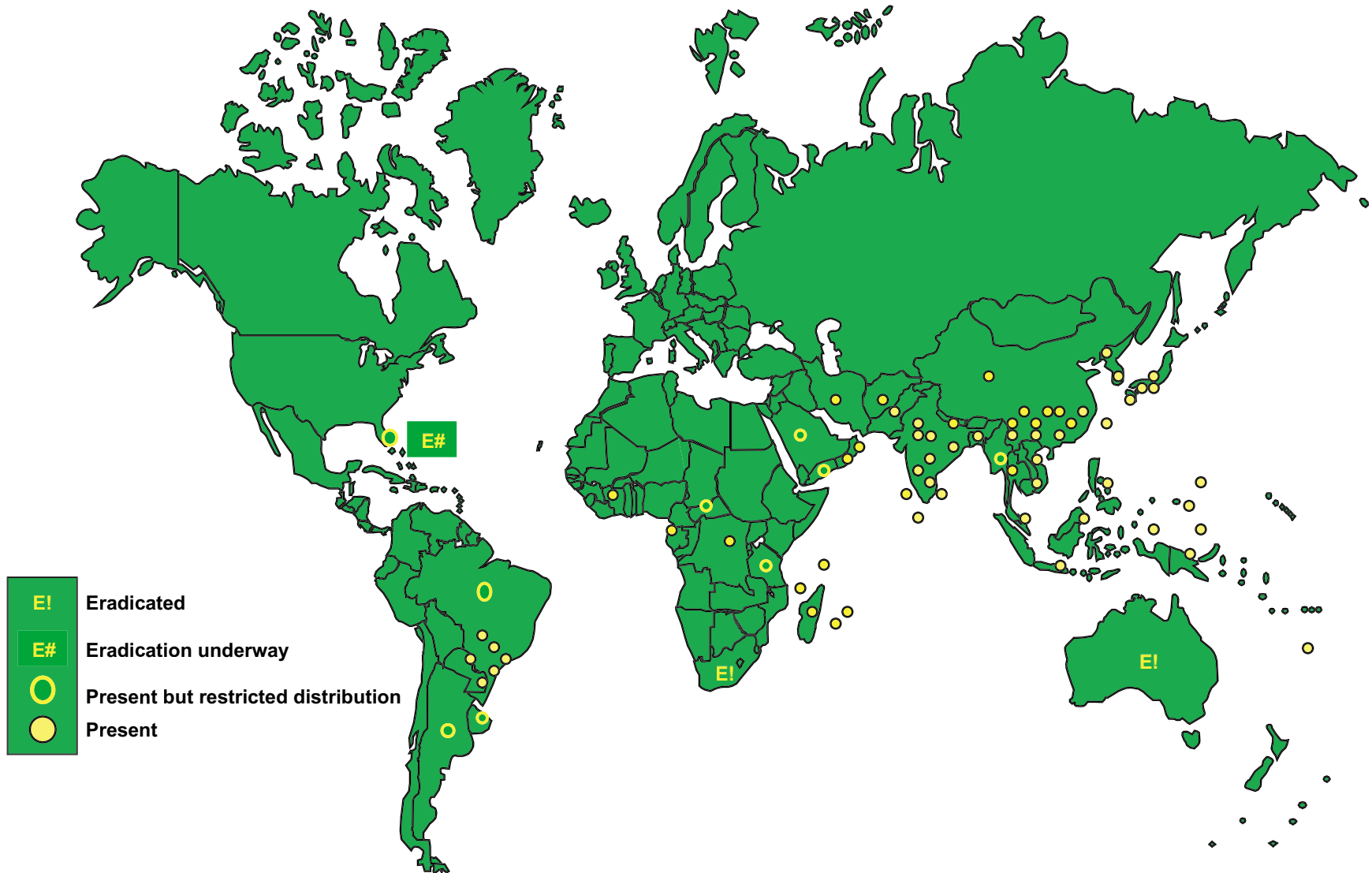
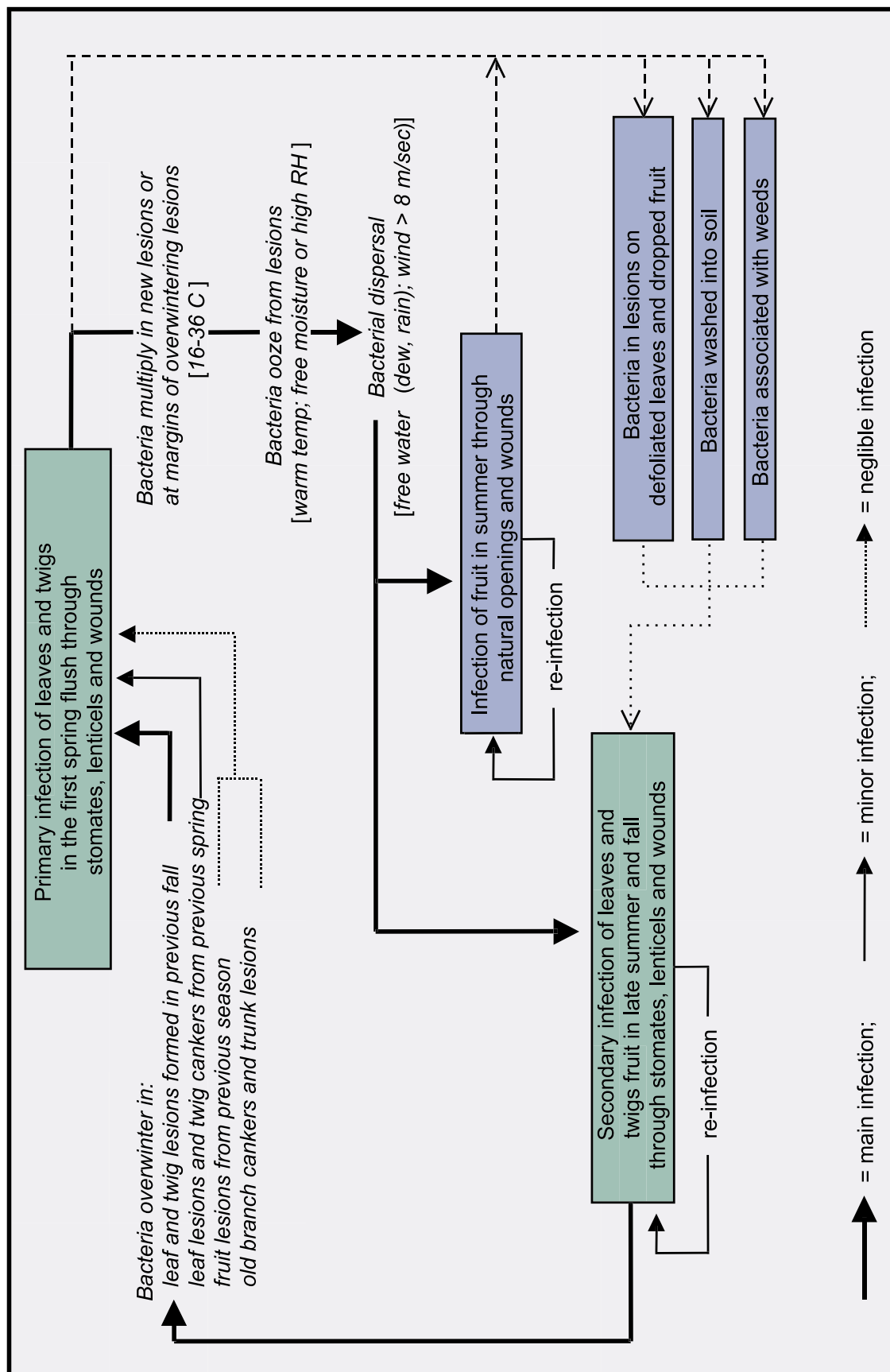


Figure 13. Disease cycle of citrus canker caused by *Xanthomonas campestris* pv. *citri*



b) Citrus black spot caused by *Guignardia citricarpa*

Citrus black spot is a fungal disease caused by *Guignardia citricarpa*. Leaves, fruit, pedicels, and twigs can be infected. The fresh market quality of infected fruit is reduced. All commercial citrus varieties are susceptible to some degree, particularly late maturing varieties.

Distribution

Citrus black spot occurs in tropical and subtropical regions with abundant rainfall in the summer, including Argentina, Brazil, Hong Kong, China, Indonesia, Japan, Kenya, Nigeria, Mozambique, Philippines, Peru, Swaziland, Taiwan, Uruguay, Venezuela, parts of South Africa and coastal areas of Australia (Fig. 14).

Symptoms

Leaf lesions are small, round, sunken necrotic spots with gray centers, each surrounded by a dark brown ring and a yellow halo. Fruit lesions are variable in appearance. The most typical symptom is hard spot and shot hole spot, which are more or less circular, depressed, brick red lesions with brown to black margins and gray necrotic tissue in the centers. These form on fruit preharvest. Pycnidia are usually, but not always, present in these spots. False melanose spots appear early on green fruit and do not contain pycnidia. These lesions may develop into hard spot and shot hole lesions toward the end of the season. Freckle spot lesions are small, orange, round, and depressed. Pycnidia may be present in these lesions. Virulent or spreading lesions are irregularly shaped and sunken. These occur on heavily infected mature fruit toward the end of the season. Numerous pycnidia develop in these lesions under high humidity.

Disease Cycle

Pathogenic and non-pathogenic strains of *G. citricarpa*, which are morphologically indistinguishable, exist. The epidemiology of black spot disease is related to the availability of inoculum in the summer; warm, wet, humid environmental conditions conducive to infection; and the effect of fruit age on susceptibility to infection. Ascospores from dead leaves on the orchard floor are the main sources of inoculum. Spore release takes place during rainfall and occasionally during irrigation. The critical period for infection starts at fruit set when rain occurs. Fruit are susceptible for 4-5 months, after which infection no longer takes place. A germ tube and appressorium result from germination of the ascospore. From the appressorium, a thin infection peg penetrates the cuticle and expands into a small mass of mycelium between the cuticle and epidermal wall where the fungus remains quiescent. After the fruit becomes fully mature, the fungus grows further into the rind tissue, producing a black spot symptom several months after infection. Although conidia from pycnidia on dead leaves or on fallen fruit on the soil can reach susceptible fruit in splashing raindrops, these are insignificant inoculum sources. However, conidia from pycnidia on late-hanging fruit with fresh lesions may be washed onto young fruit below that are still in the susceptible stage for infection. Nevertheless, conidia in pycnidia are short-lived and are not windborne. Accordingly, long-distance dissemination of epidemiologically significant *G. citricarpa* inoculum via sub-clinically infected fruit without visible lesions to regions in which environmental conditions are not conducive to infection (e.g., Mediterranean climates) is unlikely (Fig. 15).

International Dissemination

G. citricarpa-infected nursery trees or other planting stock is a primary means of long-distance dissemination of the pathogen for establishment of the disease in new areas. Inoculum is disseminated via infected, diseased leaves. Short-lived, labile conidia in pycnidia on fruit are generally not epidemiologically significant for long-distance dissemination of the pathogen.

Control

Black spot disease management is based on:

- Establishment of new orchards in disease-free areas with nursery trees or planting stock from black spot-free nurseries;
- Removal of ascospore-releasing leaves (as well as twigs and fruits with lesions) on the orchard floor during the critical infection period;
- Application of protective chemicals (e.g., copper-containing fungicides) timed to coincide with the critical infection periods; and
- Spore trapping and monitoring environmental conditions (temperature, rainfall, dew periods) to determine the time and intensity of ascospore release to facilitate timing of protective chemical fungicides.

Systems Approach

Systems Approach measures to effectively mitigate the risk of disseminating *G. citricarpa* are generally based on integrated pest management strategies, and include:

- Establish, if possible, black spot-free production groves or areas;
- Use black spot-free nursery trees or planting stock;
- Establish registered or certified groves for the production of fruit for export to monitor compliance with requirements of fruit production, post-harvest handling, and shipping;
- Establish buffer areas around fruit export groves or production areas;
- Remove potential sources of inoculum;
- Timely application of protective copper-containing fungicides at critical infection periods;
- Conduct regular disease surveys at appropriate times during the growing season, including just prior to harvest, to ensure and verify freedom from disease;
- Sample and hold fruit to verify freedom from disease before harvest;
- Maintain identity of harvested fruit from grove to packinghouses during handling and preparation for shipment;
- Prohibit packinghouses that handle and prepare fruit for export from accepting fruit from unregistered groves;
- Hold fruit in packinghouse for a suitable period under environmental conditions conducive to black spot disease development to allow manifestation of possible latent infections;
- Post-harvest surface disinfestation of fruit determined to be free of disease symptoms;
- Pack treated fruit in new, clean shipping containers marked with appropriate registration information for export;
- Issue phytosanitary certificate indicating that the fruit were produced and handled in accordance with regulation requirements;
- Inspection (and sampling if appropriate) of fruit upon arrival at port of entry;

- Remove from the export program any grove with which citrus black spot is associated at any time during the course of inspections and testing; and
- Restrict distribution in the importing country to areas in which environmental conditions are not conducive to infection and disease development.

In this Systems Approach, establishment and maintenance for certified citrus black spot disease-free production areas; use of disease-free trees; sanitation in the groves and packinghouses; timely application of fungicidal sprays; disease surveys; and restricted distribution of the commodity in the importing country are independent measures mitigating the risk of long-distance dissemination and establishment of the citrus black spot pathogen in new areas. Certification is dependent upon adequate implementation of these measures.

References

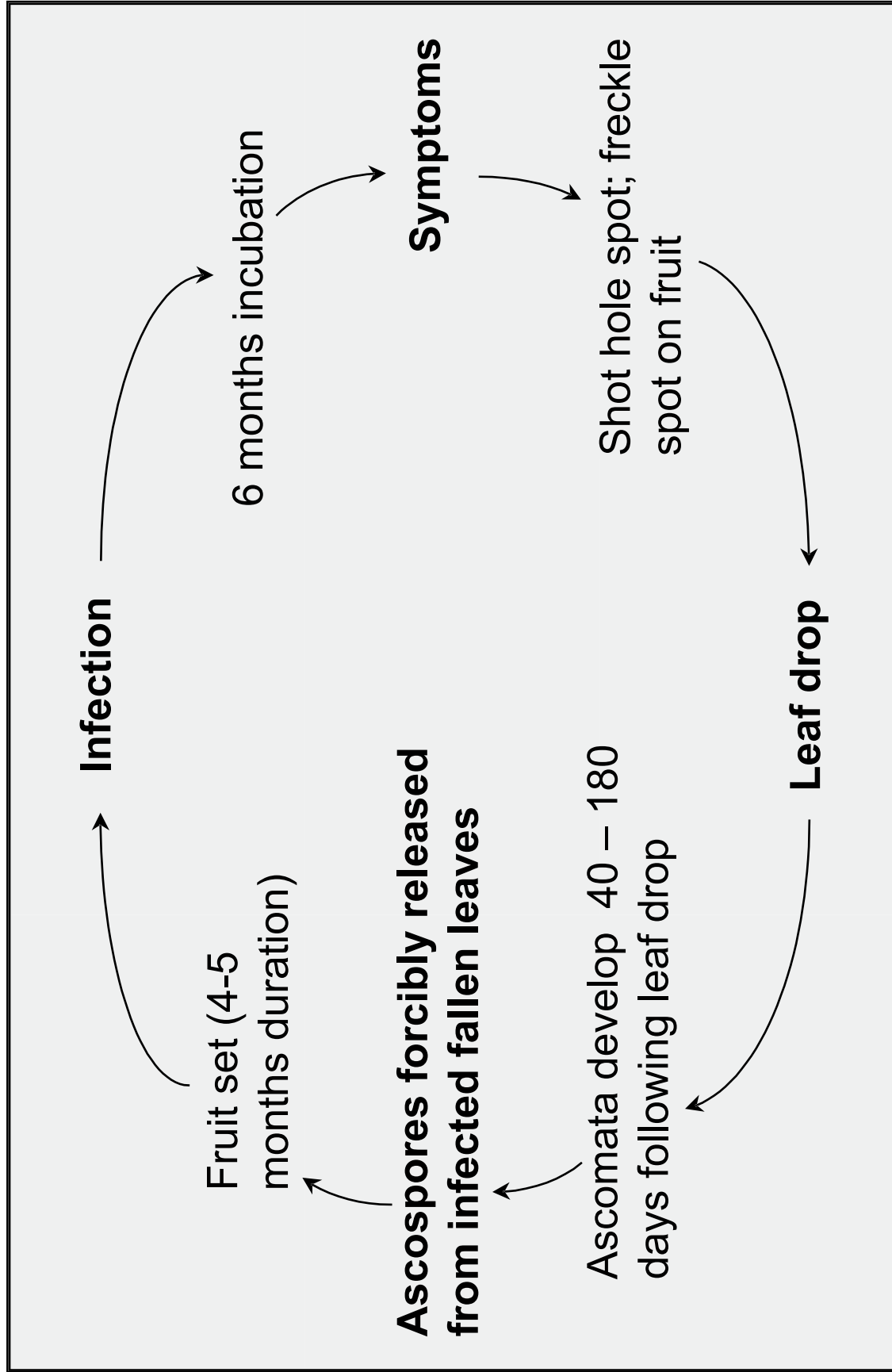
1. CAB INTERNATIONAL. 2000. Crop Protection Compendium. Wallingford, UK: CAB INTERNATIONAL.
2. Kotze, J.M. 1997. History and epidemiology of citrus black spot in South Africa. Proceedings of the International Society of Citriculture (1996) 2:1296-1299.
3. Kotze, J.M. 2000. Black Spot. In: Compendium of Citrus Diseases, 2nd Edition (L.W. Timmer, S.M. Garnsey, J.H. Graham, eds.), APS Press, pp. 24-25.
4. 7 CFR 319.56.2.



Figure 15. Citrus black spot (*Guignardia citricarpa*) distribution



Figure 16. Disease cycle of citrus black spot caused by *Guignardia citricarpa*



c) Citrus scab caused by multiple fungal pathogens

Citrus scab refers to several fungal diseases infecting fruit, leaves, and twigs of susceptible varieties. Three different citrus scab diseases are currently recognized. Citrus scab, formerly known as sour orange scab, is caused by *Elsinoe fawcettii*. Sweet orange scab is caused by *E. australis*. Tryon's scab is caused by *Sphaceloma fawcetti*. Four pathotypes of citrus scab pathogens have been differentiated based on host range. Exterior blemishes reduce the fresh market quality and value of fruit.

Distribution

Citrus scab (*E. fawcettii*) is widely distributed in humid citrus production areas. Sweet orange scab (*E. australis*) occurs in humid citrus-growing areas in South America, but has not been confirmed to occur in other areas. Tryon's scab (*S. fawcettii*) affects lemons in Australia (Fig. 17).

Symptoms

Scab pustules on leaves and fruit, consisting of fungal and host tissue, first appear as lightly raised and pink to light brown. As the pustules develop, they become warty and cracked, and become yellowish brown and eventually dark gray. Elevated protuberances may develop on the side of the leaf invaded, and a corresponding indentation forms on the opposite side. The elevation and size of lesions are affected by host species, cultivar, and age of tissue at time of infection.

Disease Cycle

Conidia are produced in acervuli on the surface of scab pustules. These spores are spread to other leaves and fruit primarily by rain splash. Hyaline conidia are fragile and die quickly under dry conditions or when exposed to direct sunlight. Spindle-shaped, colored conidia are produced on lesions following periods of moisture or dew, and can be airborne for short distances. The pathogen survives in pustules on old leaves and fruit. The optimum temperature of development of citrus scab disease is 24-27°C; however, infection occurs at higher and lower temperatures. Moisture or wetness is required for conidia production and infection. Leaves are most susceptible to infection just after emergence and are tolerant to infection by the time they are one-half to fully expanded (Fig. 18).

International Dissemination

Long-distance dispersal of the citrus scab disease pathogens is primarily via infested nursery trees or planting stock. Some pathogen dissemination may occur on equipment, especially if this is used for operations when the foliage is wet.

Control

Harvesting fruit before the spring growth flush or light hedging to remove summer flushes to reduce inoculum levels;

Avoidance of overhead irrigation, especially during the critical period of leaf expansion to reduce infection; and timely application of copper-containing fungicides to prevent inoculum build-up on shoot growth that develops prior to bloom, as well as toward the end of the bloom period if necessary.

Systems Approach

Systems Approach measures to effectively mitigate the risk of disseminating the citrus scab pathogens include:

- Establish registered or certified groves for the production of fruit for export to monitor compliance with requirements of fruit production, post-harvest handling, and shipping;
- Establish buffer areas around fruit export groves or production areas;
- Use disease-free planting stock from “clean” sources;
- Remove potential sources of inoculum;
- Timely application of protective copper-containing fungicides at critical infection periods;
- Conduct regular disease surveys at appropriate times during the growing season, including just prior to harvest, to ensure and verify freedom from disease;
- Maintain identity of harvested fruit from grove to packinghouses during handling and preparation for shipment;
- Prohibit packinghouses that handle and prepare fruit for export from accepting fruit from unregistered groves;
- Post-harvest surface disinfestation of fruit determined to be free of disease symptoms;
- Pack treated fruit in new, clean shipping containers marked with appropriate registration information for export;
- Issue phytosanitary certificate indicating that the fruit were produced and handled in accordance with regulation requirements;
- Inspect (and sample if appropriate) fruit upon arrival at port of entry;
- Remove from the export program any grove with which citrus scab is associated at any time during the course of inspections and testing; and
- Restrict distribution in the importing country to areas in which environmental conditions are not conducive to infection and disease development.

In this Systems Approach, establishment and maintenance for certified citrus scab disease-free production areas, use of disease-free trees, sanitation in the groves and packinghouses, timely application of fungicidal sprays, disease surveys, and restricted distribution of the commodity in the importing country are independent measures mitigating the risk of long-distance dissemination and establishment of the citrus scab pathogens in new areas. Certification is dependent upon adequate implementation of these measures.

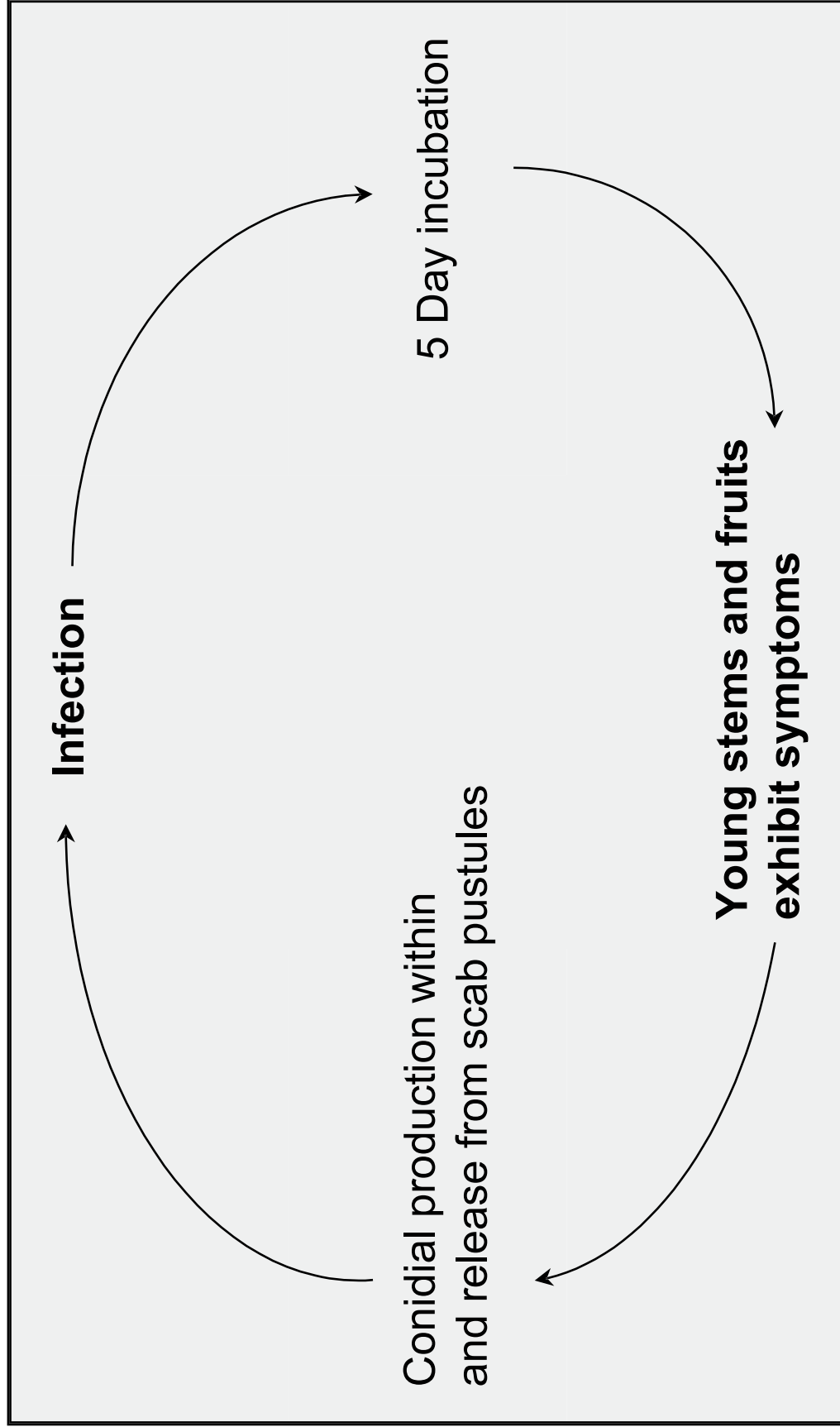
References

1. Timmer, L.W. 1997. *Elsinoe fawcettii* and *E. australis*. Crop Protection Compendium, CAB International, Wallingford, U.K.
2. Timmer, L.W. 2000. Scab Diseases. In: Compendium of Citrus Diseases, 2nd Edition (L.W. Timmer, S.M. Garnsey, J.H. Graham, eds.), APS Press, pp. 31-32
3. 7 CFR 319.56.2.

Figure 17. Citrus sweet orange scab (*Elsinoe australis*) distribution



Figure 18. Disease cycle of sweet orange scab caused by *Elsinoe australis*



d) Integration of measures for three diseases: Citrus canker, citrus black spot, and citrus scab

In the case of citrus shipped from Argentina to the United States, the pathogens targeted include *X. campestris* pv. *citri*, the cause of citrus canker; *Elsinoe australis*, the cause of sweet orange scab; and *Guignardia citricarpa*, the cause of citrus black spot.

The following mitigating steps, as well as stepwise spatial restriction of the imported fruit initially into non-citrus producing areas, were implemented during 2000 (Fig. 19).

- Citrus must be grown in a recognized citrus canker-free region (States of Catamarca, Jujuy, Salta, and Tucuman) to be eligible for export.
- The grove must be registered with the citrus fruit export program of Argentina's national plant protection organization, Servicio Nacional de Sanidad y Calidad Agroalimentaria (SENASA)
- A 150-meter buffer zone must be maintained around the grove.
- Fallen leaves, twigs and fruit must be removed from the grove prior to each season's bloom and verified by SENASA.
- Two or more copper-oil treatments are applied during fruit formation, as specified and monitored by SENASA.
- Twenty days prior to harvest, the grove and buffer area are surveyed by SENASA to verify freedom from black spot and sweet orange scab. Visual inspection of the grove is followed by fruit sampling. The sampled fruit is incubated in the laboratory for 20 days and checked for symptoms.
- Detection of black spot or sweet orange scab at any time removes the grove from the export program for the remainder of the season.
- Harvested fruit must be moved to the packinghouse in marked boxes, with fruit origin and identity maintained at all times.
- Packinghouse inspection of fruit for bruises and other damage follows a 4-5 day hold. SENASA inspects the fruit for black spot and scab.
- All fruit is surface sterilized before packing.
- Identity of the fruit's origin, certification, and shipping for export must be preserved.
- Separate packinghouses must be maintained and used exclusively for export.
- Point of entry inspection is required when the fruit arrives in the United States.
- Fruit may be distributed only to states or territories as deemed appropriate by the statutes during the years the fruit is imported.

In this Systems Approach, several steps are independent. These include (1) establishment and maintenance of certified citrus canker disease-free production areas (4 states), (2) sanitation in the groves and packinghouses, (3) timely application of fungicidal sprays, (4) disease surveys, and (5) restricted distribution within the importing country.

Establishment of buffer zones minimizes the chances of introduction, re-introduction, or distribution of the pathogens in the disease-free production areas. Removal of fallen leaves, twigs and fruit and application of fungicidal sprays are designed to reduce inoculum levels in the groves. Phytosanitary certification is dependent upon adequate implementation of all of these measures, as monitored by SENASA. Collectively, these measures reduce disease outbreaks, making the artificial spread of citrus canker, sweet orange scab, and citrus black spot pathogens into the United States from Argentina unlikely.



Figure 19. Mitigation measures employed during growth cycle of Argentine citrus

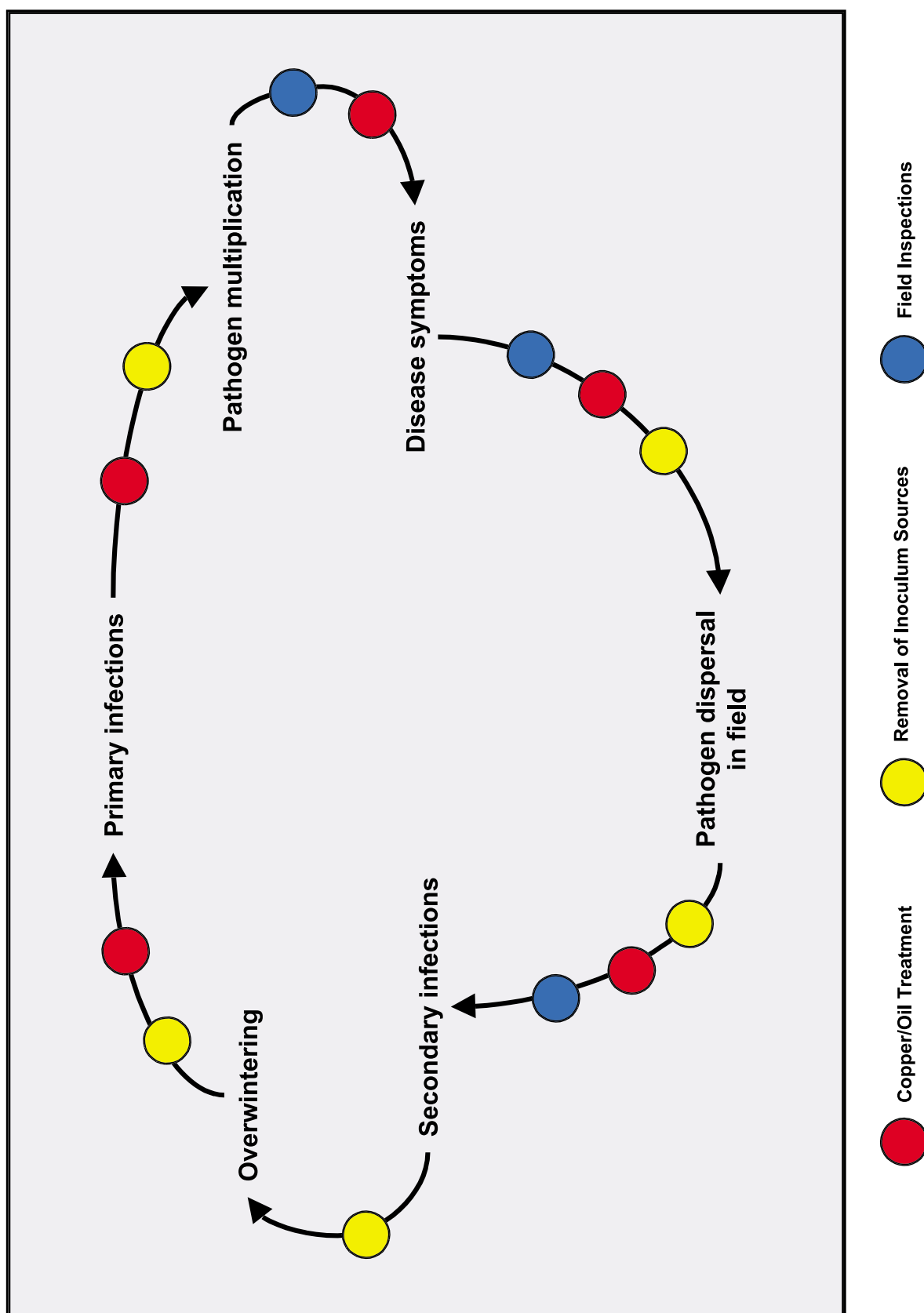
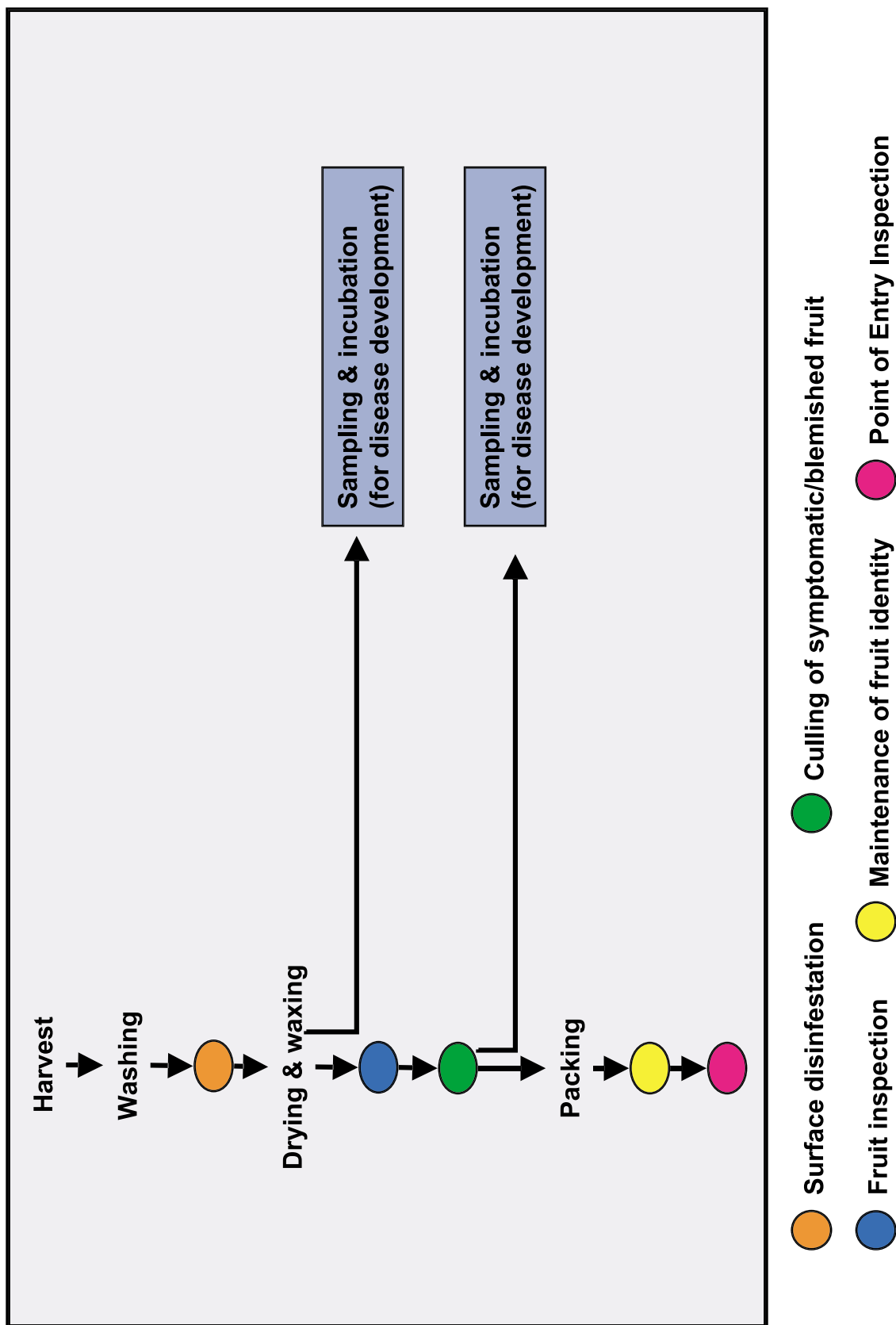


Figure 20. Mitigation measures enacted during post-harvest, packing and shipping of Argentine citrus

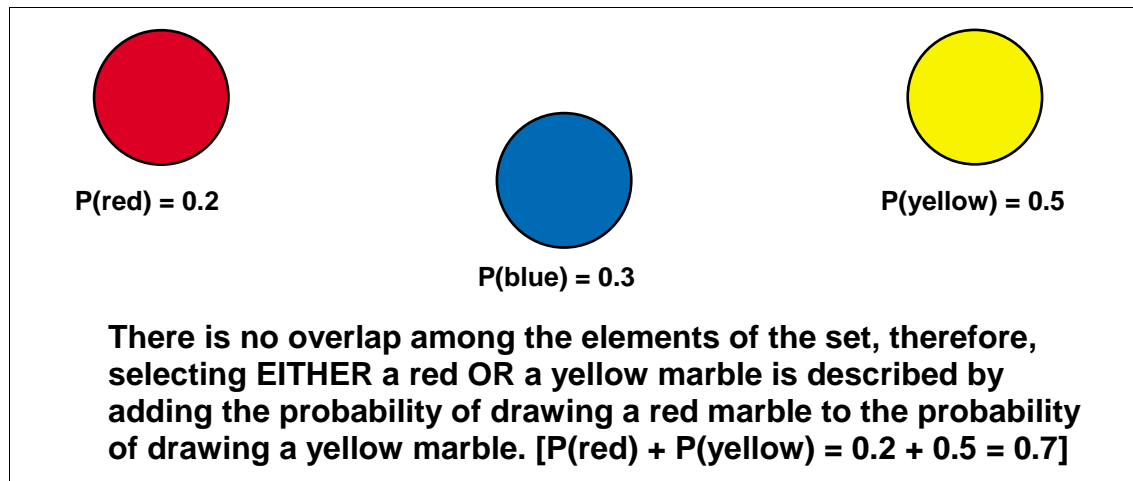


APPENDIX B – A REVIEW OF BASIC PROBABILITY THEORY

The practice of assembling a sequence of mitigating elements is based on both the theory and the empirical evidence that any single measure may not be effective at mitigating risk. A review of simple probability theory is provided to clarify the theoretical foundations of the Systems Approach.

Recall that events can be mutually exclusive. An example would be a jar containing 2 red marbles, 3 blue marbles, and 5 yellow marbles for a total of 10 marbles in the jar. Each individual marble is either red, or blue, or yellow. There is no overlap. The probability of picking a red marble out of the jar is $2/10$ or $P(\text{red}) = 0.2$. The probability of picking a yellow marble is $5/10$ or $P(\text{yellow}) = 0.5$. The probability of picking a red marble OR a yellow marble is $P(\text{red}) + P(\text{yellow}) = 0.2 + 0.5 = 0.7$. (Figure 21 illustrates this scenario.)

Figure 21. Demonstration of probability theory – no overlapping events

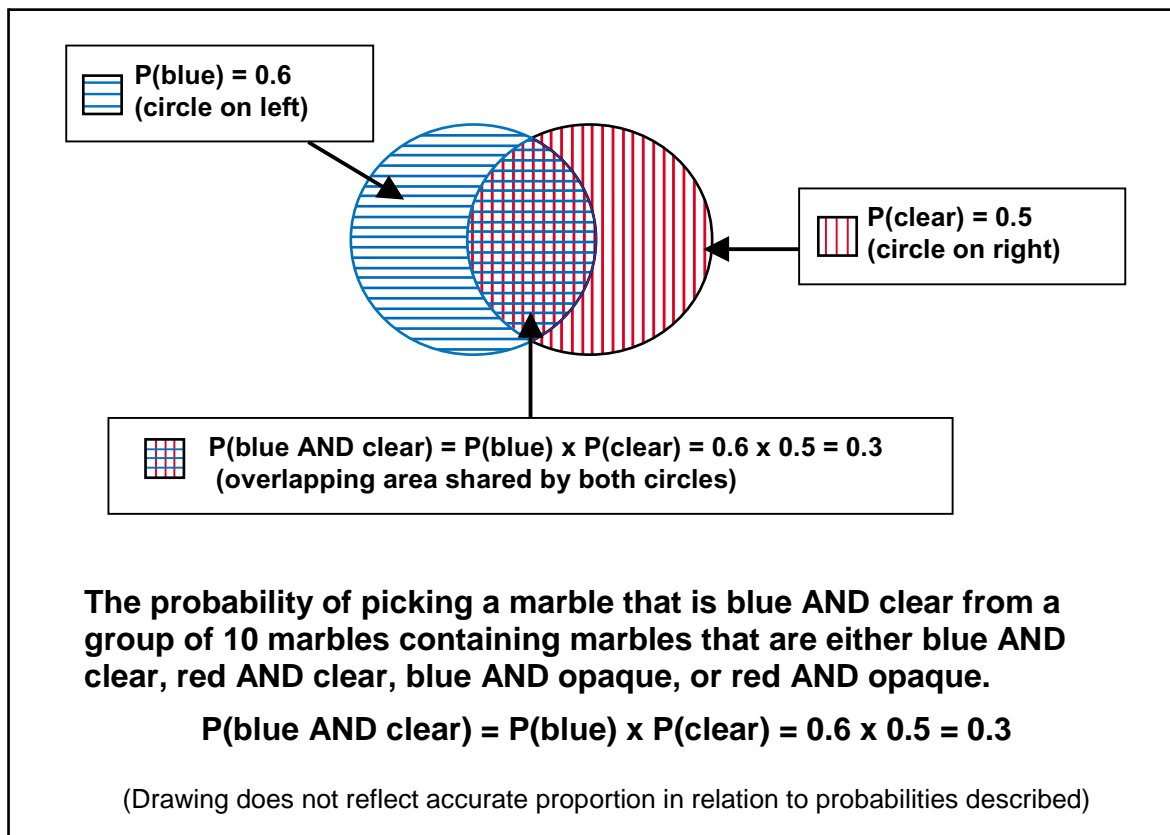


An example of a mutually exclusive event in plant pathogen control would be individual fruits, plants or units in a shipment or consignment of a plant commodity that are either infected or not infected. The unit cannot be both infected and uninfected. There is no overlap. The pathogen is either detected then eliminated by a mitigation measure OR it is not. Let a jar of 100 marbles represent a consignment or shipment of a particular commodity. Twenty red marbles represent the individual fruits, plants or other discrete units (cartons, bags, etc.) that are infected or infested, as the case may be. The pest prevention goal is to reduce the number of individual infected fruits, plants or other units to an acceptable level per consignment. Suppose that the acceptable level is determined to be only one infected fruit, plant or unit. In the Systems Approach, the question is what combination of independent measures can be applied to ensure that no more than one fruit, plant or unit in each consignment will be infected or infested.

Another possibility is that events overlap. Imagine a different jar, this one contains ten marbles, 60% of the ten marbles are blue, 40% are red, and 50% of each group of colored marbles are clear and 50% are opaque.

The probability of drawing a blue marble is $P(\text{blue}) = 0.6$. The probability of drawing a clear marble is $P(\text{clear}) = 0.5$. The probability of drawing a marble that is blue AND is clear is $P(\text{blue AND clear}) = P(\text{blue}) \times P(\text{clear}) = 0.6 \times 0.5 = 0.3$. Another way of thinking of this is that of the 60% that are blue, 50% (or half) of the blue are also clear. One-half of 6 is 3, so there are 3 marbles, out of 10, that are both blue AND clear. (As in Fig. 22, below)

Figure 22. Demonstration of probability theory – overlap is chosen area

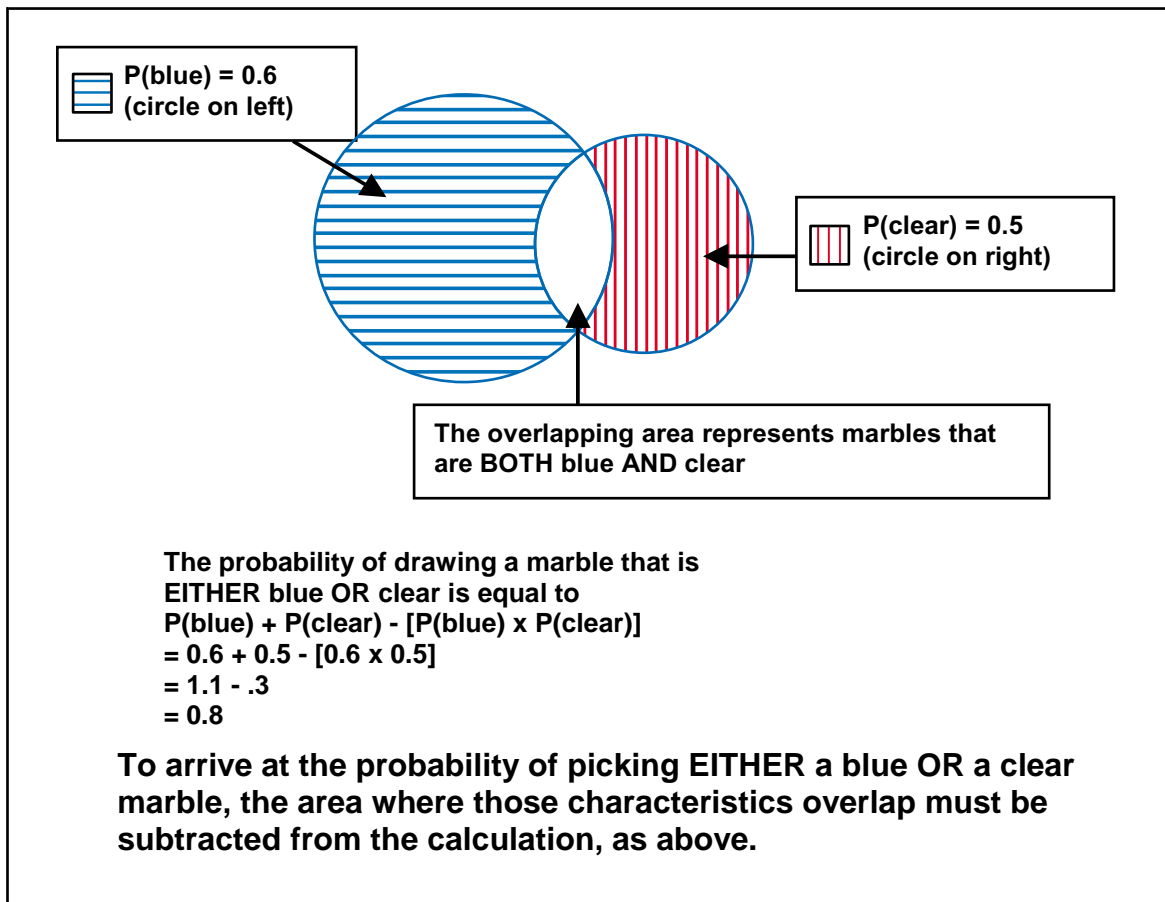


As additional descriptive elements are introduced, the probability calculations follow the same pattern. Suppose in the example above, some marbles are big and some are small. The chance of picking a small, blue, clear marble = $P(\text{small}) \times P(\text{blue}) \times P(\text{clear})$.

In quarantine areas, a single crop unit (fruit, plant, carton or bag) within a shipment could be infected with a pathogen AND detection of the pathogen could fail. If the probability of being infected is $P(\text{infected}) = 0.05$ and the probability of the mitigation measure failing is $P(\text{mitigation failed}) = 0.1$ then the probability of the pathogen being present but not eliminated by the mitigation measure is $P(\text{present AND mitigation failed}) = P(\text{present}) \times P(\text{mitigation failed}) = 0.05 \times 0.1 = 0.005$.

If we are interested in all instances in an overlapping-events scenario in which EITHER OR BOTH events occur, the diagram resembles Figure 22.

Figure 23. Demonstration of probability theory – overlap is not “double-counted”



We want to include all of both circles. In this case, if we add the 2 probabilities together we would count the overlap area twice – once as being part of the blue circle and again as being part of the checkered circle that represents all the clear marbles. The sum would give us a clearly impossible probability of 1.1. So, instead, as in Figure 23 (above), we calculate the probability of the overlap as $P(\text{blue}) \times P(\text{clear})$. If we now subtract the probability value defined by the area of overlap between the circles from the sum of the area of the two circles, we will count the overlap area only once. $P(\text{blue OR clear}) = P(\text{blue}) + P(\text{clear}) - (P(\text{blue}) \times P(\text{clear})) = 0.6 + 0.5 - (0.6 \times 0.5) = 1.1 - 0.3 = 0.8$.

The accuracy of this calculation is demonstrated by considering the 10 marbles again. To choose EITHER a blue OR clear marble, the *only* marbles we *may not* choose are the two that are BOTH red AND opaque.

Consider a piece of fruit that can become infected from one or more exposures to a plant pathogen. If the probability of a pathogen infecting a commodity in an area of low pathogen occurrence is

P(pathogen in low-occurrence zone) = 0.05 and the probability of pathogen-infected planting material being certified as pathogen-free is 0.01, then the probability of a commodity becoming infected as a result of a pathogen entering the area and/or coming in on certified clean planting material can be described:

$$0.05 + 0.01 - (0.05 \times 0.01) = 0.06 - 0.0005 = 0.0595.$$

Basic probability theory, coupled with qualitative assessment, provides a meaningful method of predicting the level of protection achievable by a specific combination of mitigation measures.



GLOSSARY

Terms listed below are used in the text, or are common to the discussions and research on pest risk management. These have been taken from the United Nations Food and Agriculture Organization's Glossary of Phytosanitary Terms (1999), International Standard for Phytosanitary Measures, Pub. No. 5. Terms appearing in **boldface type** are defined elsewhere in the glossary.

| | |
|------------------------------------|---|
| Area | A defined region or part of a country, or all or parts of several countries. (As defined in the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures.) |
| Area of low pest prevalence | An area, whether all of a country, part of a country, or all or parts of several countries, as identified by the competent authorities, in which a specific pest occurs at low levels and which is subject to effective surveillance, control or eradication measures. |
| Certificate | An official document that attests to the phytosanitary status of any consignment affected by phytosanitary regulations . |
| Commodity | A type of plant , plant product or other regulated article being moved for trade or other purposes. |
| Consignment | A quantity of plants , plant products and/or other regulated articles being moved from one country to another and covered by a single phytosanitary certificate . |
| Control (of a pest) | Suppression, containment , or eradication of a pest population. |
| Entry (of a consignment) | Movement through a point of entry into an area . |
| Entry (of a pest) | Movement of a pest into an area . (See introduction) |
| Eradication | Verifiable elimination of a pest from an area via the use of phytosanitary measures . |

| | |
|--|--|
| Establishment | Perpetuation, for the foreseeable future, of a pest within an area after entry . |
| Exotic | Not native to a particular country or ecosystem (applied to organisms introduced as a result of human activities). |
| Field | A plot of land with defined boundaries within a production area on which a commodity is grown. |
| Fresh | Living. Neither dried, deep-frozen or otherwise conserved or rendered dormant. |
| Fruits and vegetables | Fresh parts of plants intended for consumption or processing. |
| Fumigation | Treatment with a chemical agent that reaches the commodity wholly or primarily in a gaseous state. |
| Germplasm | Plants intended for use in breeding or conservation programs. |
| Growing season | Period of the year or when plants will actively grow in an area . |
| Hitch-hiker (pest) | A pest that is carried by a commodity and, in the case of plants and plant products , does not infest those plants or plant products . |
| Host range | Species of plants capable, under natural conditions, of sustaining a specific pest . |
| Infestation | Presence in a commodity of a living pest of the plant or plant product concerned. Infestation includes infection . |
| Inspection | Visual examination of plants , plant products or other regulated articles to determine if pests are present and/or to determine compliance with phytosanitary regulations . |
| International Plant Protection Convention | International Plant Protection Convention, (IPPC) as deposited with United Nations Food and Agriculture Organization (FAO) in Rome in 1951 and as subsequently amended. |

International Standard for Phytosanitary Measures

Introduction

An international standard adopted by the Conference of FAO; the Interim Commission on **Phytosanitary Measures** or the Commission of **Phytosanitary Measures**, established under the **IPPC**.

IPPC

The **entry** of a **pest** resulting in its **establishment**.

See **International Plant Protection Convention** (above) .

ISPM

See **International Standard for Phytosanitary Measures** (above) .

Monitoring

An ongoing process to verify phytosanitary situations

National Plant Protection Organization

Official service established by a government to discharge the functions specified by the **IPPC**. (**NPPO**)

NPPO

National Plant Protection Organization (above) .

Occurrence

The presence in an **area** of a **pest** whether indigenous or **introduced** and not **eradicated**.

Official

Established, authorized or performed by a **National Plant Protection Organization**.

Pathogen

Microorganism causing disease.

Pathway

Any means that allows the **entry** or **spread** of a **pest**.

Pest(s)

Any species, strain or biotype of **plant**, animal, or pathogenic agent injurious to **plants** or **plant products**.

Pest free area

An **area** in which a specific **pest** does not occur as demonstrated by scientific and in which, where appropriate, this condition is being **officially** maintained and **monitored**.

Pest risk analysis

The process of evaluating biological or other scientific and economic evidence to determine whether a **pest** should be regulated and the strength of any **phytosanitary measures** to be taken against it.

Pest risk management

The decision-making process of reducing the risk of **introduction** of a **quarantine pest**.

| | |
|----------------------------------|--|
| Phytosanitary certificate | A certificate - modeled on IPPC guidelines - verifying the condition of a commodity , or area with regard to infestation or freedom from pests . |
| Phytosanitary legislation | Basic laws granting legal authority to a National Plant Protection Organization from which phytosanitary regulations may be drafted. |
| Phytosanitary measure | Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of pests |
| Phytosanitary procedure | Any officially prescribed method for performing inspections, tests, surveys, or treatments in connection with regulated pests . |
| Phytosanitary regulation | Official rule to prevent the introduction and/or spread of pests , by regulating the production, movement or existence of commodities or other articles, or the normal activities of persons, and by establishing procedures for phytosanitary certification . |
| Plant(s) | Living plants and parts thereof, including seeds and germplasm . |
| Plant products | Manufactured or unmanufactured material of plant origin that, by their nature or that of their processing, may create a risk for the introduction and spread of pests . |
| Plant quarantine | All activities designed to prevent the introduction and/or spread of quarantine pests or to ensure their official control . |
| Plants in tissue culture | Plants in an aseptic medium in a closed container. |
| POE | Point of entry (see below) |
| Point of entry | Airport, seaport or land border point officially designated for the importation of consignments , and/or entrance of passengers. |
| Post-entry quarantine | Quarantine applied to a consignment after entry . |
| PRA | Pest risk analysis (above) . |

| | |
|---|---|
| Prohibition | A phytosanitary regulation forbidding the importation of specified pests or commodities . |
| Quarantine | Official confinement of regulated articles for observation and research or for further inspection, testing and/or treatment . |
| Quarantine area | An area within which a quarantine pest is present and is being officially controlled . |
| Quarantine pest | A pest of potential economic importance to the area of importation that is either not present or present but not widely distributed and being officially controlled . |
| Region | The combined territories of the member countries of a Regional Plant Protection Organization . |
| Regional Plant Protection Organization | An intergovernmental organization functioning under the provisions of Article IX of the IPPC . [For example, North American Plant Protection Organization (NAPPO) , European and Mediterranean Plant Protection Organization |
| Regulated article | Any plant, plant product , storage place, packaging, conveyance, container, soil and any other organism, object or material capable of harboring or spreading pests , deemed to require phytosanitary measures . |
| Restriction | A phytosanitary regulation allowing the importation or movement of specified commodities subject to specific requirements. |
| Seeds | Seeds for planting not for consumption or processing. |
| Spread | Expansion of the geographical distribution of a pest within an area . |
| Standard | Document established by consensus and approved by a recognized body that provides for common and repeated use of applicable rules, guidelines or characteristics for activities or their results. |

Survey

An **official** procedure conducted over a defined period of time to determine the characteristics of a **pest** population or to determine which species **occur** in an **area**.

Test

Official examination, other than visual, to determine if **pests** are present, or to identify **pests**.

Transparency

The principle of disclosing, at the decision-making level, the rationale behind **phytosanitary measures**.

Treatment

Officially authorized procedure for the killing or removal of **pests**, or for rendering pests infertile.



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NOTES

